Chapter 3 -- Best Management Practices for Urban Sites

Introduction

This chapter describes some of the key issues and selection criteria for Stormwater Best Management Practices. Its overall theme is that to manage both the large storms and pollutant loading usually requires a series of practices tailored to a particular site or modified based on the receiving waters. Factors to be considered include land use, physical constraints, watershed context, required capacity, pollutant removal needs, environmental benefits, and maintenance issues.

This chapter provides detailed descriptions of practices recommended for the four case study scenarios described in Chapter Three. These include both small-scale practices based on simple technologies like rain barrels, as well as more complex techniques such as green rooftop systems. Each includes a discussion of appropriate applications, costs, benefits and limitations, as well as design standards and maintenance requirements.

The practices described are:

- Rain Barrels and Cisterns
- Stormwater Planters
- Permeable Paving
- Open Channels
- Stream Daylighting
- Vegetated Buffers
- Stormwater Wetlands
- Bioretention
- Green Rooftop Systems

Planners, engineers and municipal officials should check local, state and federal ordinances to ensure that project designs are in conformance with all applicable laws and regulations. In particular, stormwater management is regulated by RIDEM and stormwater project designers and municipal staff should consult with RIDEM's Stormwater Design and Installation Standards Manual for the latest specific criteria and procedures regarding stormwater system design.

Selecting Stormwater Practices

The selection of appropriate stormwater practices for any given site involves a combination of the process of elimination and the process of addition. Typically, no single practice will meet all stormwater management objectives. Instead, a series of practices are generally required. Certain practices can be eliminated from consideration, based on one limiting factor. But several practices may ultimately "survive" the elimination process. The most appropriate practices are those that are both feasible, cost effective, <u>and</u> achieve the maximum benefits for watershed protection.

Structural stormwater practices are frequently designed to meet either *water quality* and/or *water quantity* control requirements. *Water quality* facilities are typically applied to control and treat pollutants that wash off urban land surfaces and are designed for a prescribed volume of runoff, which is usually relatively small and is related to the so-called "first flush" of stormwater. The first flush is generally considered to be between the first half-inch of rainfall up to the first inch of rainfall and is significantly higher in pollutant concentrations than the stormwater from subsequent rainfall. Documented stormwater quality monitoring shows that, in most cases, the majority of contaminants that wash off the land surface will be carried away in the first flush of stormwater in any given storm. Therefore, stormwater treatment practices can remove the greatest proportion of contaminants by treating the first flush, which allows practices to be sized for a relatively modest volume of runoff. In Rhode Island, the **one-inch of runoff from impervious surfaces** is used as a basis for sizing water quality control facilities (RIDEM, 1993 or most recent addition "Stormwater Design and Installation Standards Manual).

Water quantity facilities are typically designed to control increases in peak flow rates and volumes associated with larger storms in the range of the 2-year frequency storm up to the 100-year storm. The 2-year frequency storm is defined as the precipitation amount that has a likelihood of occurring once every two years, or has a 50% chance of occurring in any given year. In Rhode Island, proposed projects must control and maintain post-development peak discharge rates from the **2-year and 25-year storm events** at pre-development levels. In addition, a downstream analysis of the 100-year storm event is required to ensure no adverse impact at this precipitation value, and if impacts are evident, controls may be necessary.

The basic considerations for arriving at the most appropriate practice or suite of practices at any given site or project are typically governed by the following factors:

Land use.
Which practices are best suited for the proposed land use at the site in question? Some practices are ill suited for certain land uses. For example, infiltration practices should not be utilized where runoff is expected to contain high levels of dissolved constituents, such as metals or hydrocarbons or where prior subsurface contamination is evident. Increased hydraulic loading to contaminated soils can accelerate pollutant migration and/or leaching into underlying groundwater.

Physical feasibility factors.
Are there certain physical constraints at a project site that restrict or preclude the use of particular practices? This involves an assessment of existing onsite structures, soils, drainage area, water table, slope or elevation constraints at a particular site. For example, the rule-of-thumb minimum drainage area for constructed wetlands is 25-acres unless groundwater interception is likely. Constructed wetlands also can consume a significant land area.

Watershed factors.
What watershed protection goals are needed within watershed that the site drains to? This set of factors involves screening out those practices that might contradict overall watershed protection strategies, or eliminating management requirements where they are unnecessary or inappropriate. For example, practices that maximize pollutant and toxicity reduction are typically relevant in urban watersheds such as the lower Blackstone and water *quantity controls* are not necessary for discharges to tidal waters or large river systems. Regulatory requirements under the Clean Water Act, Total Maximum Daily Load (TMDL) reduction requirements and/or interests from watershed associations may dictate the type, location, and design requirements for stormwater management practices.

Stormwater management control capability.
What is the capability of a particular stormwater practice or suite of practices to meet the multiple objectives of water quality controls, and/or water quantity controls? Certain practices have limited capabilities to manage a wide range of storm frequencies. For example, the filtering practices are generally limited to water quality treatment and seldom can be utilized to meet larger storm stormwater management objectives.

Pollutant removal capability.
How do each of the stormwater management options compare in terms of pollutant removal? Some practices have a better pollutant removal potential than others or have a better capability to remove certain pollutants. For example, stormwater wetlands provide excellent total suspended solids (TSS) removal but only modest total nitrogen (TN) removal.

Environmental and maintenance considerations.
Do the practices have important environmental benefits or drawbacks or a maintenance burden that might influence the selection process? Some practices can have significant secondary environmental impacts that might preclude their use in certain situations. Likewise, some practices have frequent maintenance and operation requirements that are beyond the capabilities of the owner. For example, infiltration practices are generally considered to have the highest maintenance burden because of a high failure history and consequently, a higher pre-treatment maintenance burden and/or replacement burden. Infiltration practices should not be used where prior subsurface contamination is present due to the increased threat of pollutant migration associated with increase hydraulic loading from infiltration systems.

Rain Barrels & Cisterns

Introduction

Rain barrels and cisterns are automatic water collection systems that store runoff from stormwater to be used later for activities such as lawn and garden watering. Reuse of stormwater runoff is beneficial to the environment because the stored water would otherwise enter the storm sewer, increasing the volume of discharge into receiving waters. In older cities, such as many in Rhode Island with combined sewer systems, the addition of stormwater also contributes to sanitary sewer overflows. Rain barrels are small barrels (50 to 250 gallons) placed on the end of a down spout that store runoff for future irrigation use (Figure 1). A cistern is similar to a rain barrel, but it has much greater storage capacity and can be designed to collect runoff from impervious areas (roof and/or pavement), filter the water, store it, and use it for watering lawns and gardens. Cisterns can also be designed for household uses such as toilet flushing, and clothes washing (Figure 2).

Figure 1-A. Rain Barrel
Source: www.rdrop.com

Figure 1-B. Rain Barrel
Source: Claytor

The basic components of any rain barrel are relatively simple. Rain barrels consist of an actual barrel, often made of plastic, a sealed yet removable child and animal resistant top to keep potential pests out, connections to the downspout, a runoff pipe and a spigot. A number of accessories can be added, such as additional barrels for expanded storage volume, a water diversion soaker hose, an automatic overflow, or an automatic irrigation overflow.

Cisterns can be constructed of any impervious, water-retaining material. They can be located either above or below ground and can be constructed on-site or pre-manufactured and then placed on-site. The basic components of a cistern include: a secure cover, a leaf/mosquito screen, a coarse inlet filter with clean-out valve, an overflow pipe, a manhole, a sump, a drain for cleaning, and an extraction system (tap or pump). Additional features might include a water level indicator, a sediment trap, or an additional tank for more storage volume.

Facility Application

Rain barrels and cisterns can be used in most areas (residential, commercial, and industrial) due to their minimal site constraints relative to other stormwater management practices. They

Figure 2-A. Cisterns
Source: Chesapeake Bay Foundation

can be applied to manage almost every land use type from very dense urban areas to more rural residential areas. The sizes of barrels or cisterns are directly proportional to their contributing drainage areas.

Benefits

Rain barrels and cisterns are low-cost water conservation devices that can reduce runoff volume for smaller storm events, and delay and reduce peak runoff flow rates. By storing and diverting runoff from impervious areas such as roofs, these devices reduce the undesirable impacts of runoff that would otherwise flow swiftly into receiving waters and contribute to flooding and erosion. Stored water from rain barrels and cisterns can help reduce domestic water consumption, which ultimately reduces the demand on municipal water systems and supplies.

Figure 2-B. Cistern
Source: Portland Stormwater Management Manual

Limitations

Rain barrels and cisterns are physically limited by their size. Once the rain barrels or cisterns are full, additional stormwater will overflow onto surrounding areas and/or into the downstream drainage system.

Sizing and Design Considerations

The sizing for rain barrels and cisterns is a function of the impervious area that drains to the device. The basic equation for sizing a rain barrel or a cistern is as follows:

$$Vol = A * R * 0.90 * 7.5 \text{ gals/ft}^3$$

where:

Vol	= Volume of rain barrel or cistern (gallons)
A	= Impervious surface area draining into barrel or cistern (ft^2)
R	= Rainfall (feet)
90.90	= Loss to system (unitless)
5.5	= Conversion factor (gallons per cubic foot)

Figure 2-C. Cistern
Source: Texas Guide to Rainwater Harvesting, Texas Water Development Board, Austin, TX

A cistern can be located beneath a single downspout or one large cistern can be located such that it collects stormwater from several sources. Due to the size of rooftops and the amount of contributing impervious area, increased runoff volume and peak discharge rates for commercial and industrial sites may require large capacity cisterns. Cisterns can be located above or below ground, and can be constructed on site or pre-manufactured and then placed on site. Cistern sizes can vary from hundreds of gallons for residential uses to tens of thousands of gallons for commercial and/or industrial uses.

Cost

Rain barrels are relatively low cost, pre-manufactured systems averaging about $120, minus downspout and other accessories (UGRC). Basic supplies to construct a barrel can be as low as $20. The cost for cisterns can vary greatly depending on its size, material and location (above or below ground). The following are representative costs for pre-manufactured cisterns, not including labor and accessory costs (Table 1).

Maintenance

Maintenance requirements for rain barrels and cisterns are minimal and consist of bi-annual inspections of the unit. The following components should be inspected and either repaired or replaced as needed (Table 2).

References

Kessner, K., 2000. How to Build a Rainwater Catchment Cistern. The March Hare, Summer 2000, Issue 25, http://www.dancingrabit.org/newletter/

Low Impact Development Center, Inc. (LID) http://www.lid-stormwater.net/intro/sitemap.htm#permpavers

The Urban Garden Rain Center (UGRC), Rain barrel Web page, www.urbangarden.com

Table 1: Cost Guide – Pre-manufactured Cisterns (LID)

Material	Cost, Small System	Cost, Large System
Galvanized Steel	$225 for 200 gallons	$950 for 2,000 gallons
Polyethylene	$160 for 165 gallons	$1,100 for 1,800 gallons
Fiberglass	$660 for 350 gallons	$10,000 for 10,000 gallons
Fiberglass/Steel Composite	$300 for 300 gallons	$10,000 for 5,000 gallons

The average cost for a typical manually-constructed cistern for residential use made of reinforced concrete (3,000 gallons), minus labor, would be approximately $1,000 (Kessner, 2000).

Table 2: Maintenance of Rain Barrels and Cisterns (LID)

Rain Barrels	Cisterns
Roof Catchment – ensure that no particulate matter or other parts of the roof are entering the gutter and downspout to the rain barrel.	**Roof Catchment** –ensure that no particulate matter or other parts of the roof are entering the gutter and downspout to the cistern.
Gutters – ensure that no leaks or obstructions are occurring.	**Gutters** – ensure that no leaks or obstructions are occurring.
Downspouts – ensure that no leaks or obstructions are occurring.	**Downspouts** – ensure that no leaks or obstructions are occurring.
Entrance at Rain Barrel – ensure that no leaks or obstructions are occurring.	**Roof Washer and Cleanout Plug** – inspection and replacement as needed.
Rain Barrel – check potential leaks, including barrel top and seal.	**Cistern Screen -** inspection and replacement as needed.
Runoff/Overflow Pipe – check that overflow is draining in non-erosive manner.	**Cistern Cover -** inspection and replacement as needed.
Spigot – ensure that it is functioning correctly.	**Cistern** – inspection and cleanout, should include inflow and outflow pipes.
Any accessories – such as rain diverter, soaker hose, linking kit or additional gutters.	**Cistern Overflow Pipe -** inspection and replacement as needed.
	Any accessories – inspection and replacement as needed, such as sediment trap.

Stormwater Planters

Introduction

Stormwater planters are small-scale, stormwater treatment systems comprised of organic soil media and plants in a confined planter box. Stormwater planters are simply “bioretention in-a-box” (see section on bioretention, page 88). Planters generally look like large vaulted plant boxes and can contain anything from basic wildflower communities to complex arrangements of trees and flowering shrubs. The method combines physical filtering and adsorption with bio-geochemical processes to remove pollutants.

There are three basic variations of the stormwater planters: the contained system, the infiltration system, and the flow-through system. Contained planters are typical large self-contained planters found on terraces, desks and sidewalks (Figure 1). Infiltration planter boxes are designed to allow runoff to filter through the planter soils and then infiltrate into the native soils (Figure 2). Flow-through planter boxes are designed with impervious bottoms or placed on impervious surfaces. This flow-through system consists of an inflow component (usually a downspout), a treatment element (soil medium), an overflow structure, plant materials, and an underdrain collection system to divert treated runoff back into the downstream drainage system (Figure 3).

Figure 1: Contained Planter
Source: Chicago City Hall, (American Society of Landscape Architects, asla.org)

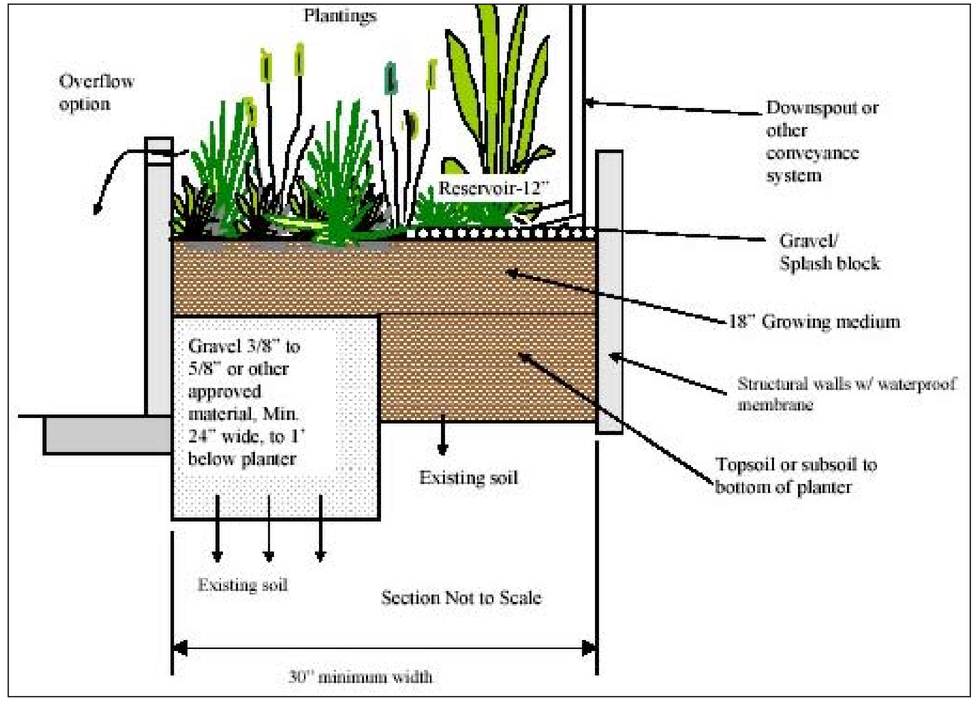

Figure 2: Infiltration Planter
Source: City of Portland, Stormwater Management Manual, 2002

Facility Application

Stormwater planters are ideally adapted for ultra-urban redevelopment projects (Figure 4). Roof runoff can be directed from the downspout directly into the planters. Runoff from rooftop areas contains nutrients carried in rainwater, sediments and dust from rooftops, and bacteria from bird traffic. These pollutants can all be attenuated to a significant degree during small rain events. Planters can be effective in reducing the velocity and volume of stormwater discharge from rooftops areas. Another benefit of stormwater planters is the relatively low cost. These are small self-contained units that can be easily constructed without heavy-duty excavation that accompanies other BMPs. Stormwater planters also add aesthetic elements by improving the surrounding streetscape

These systems are rarely used to manage large storms. Any storm greater than the infiltration capacity of the soil will flood the planters and will overflow onto the street or into an overflow pipe. Planters should be designed to attenuate water no more than 3 to 4 hours after an average storm. The topsoil (soil medium) should have an infiltration rate of 2 inches per hour. The drainage layer (sand or gravel) should have a minimum infiltration rate of 5 inches per hour.

Infiltration planters are also known as "exfilters". An exflter is a system designed to filter runoff through the soil media before infiltration into the underlying soil (Figure 1). If poor soils, high groundwater, or soil contamination exists that would prevent conventional infiltration, then a contained or a flow-through stormwater planter is recommended.

Benefits

Stormwater planters can have many benefits when applied to redevelopment and infill projects in urban centers. The most notable benefits include:

- Effective pollutant treatment for solids, metals, nutrients and hydrocarbons
- Groundwater recharge augmentation (if designed as an exfilter, where soils, land uses, and groundwater elevations permit)
- Micro-scale habitat
- Aesthetic improvement to otherwise hard urban surfaces
- Ease of maintenance, coupling routine landscaping maintenance with effective stormwater management control
- Relatively low cost relative to other practices

Limitations

The application of stormwater planters is limited to treating only roof runoff. It is also limited in the amount of runoff it can receive. Infiltration and flow through planter boxes should receive drainage from no more than 15,000 square feet of impervious area. Any storm event greater than 2 inches per hour (topsoil infiltration rate) will start to pond in the planters and eventually overflow, onto the street or into the underdrain system and therefore will not be treated for water quality.

Sizing and Design Considerations

The basis for this guideline relies on the principles of Darcy's Law, where liquid is passed through porous media with a given head, a given hydraulic conductivity, over a given timeframe. The basic equation for sizing stormwater planters is as follows:

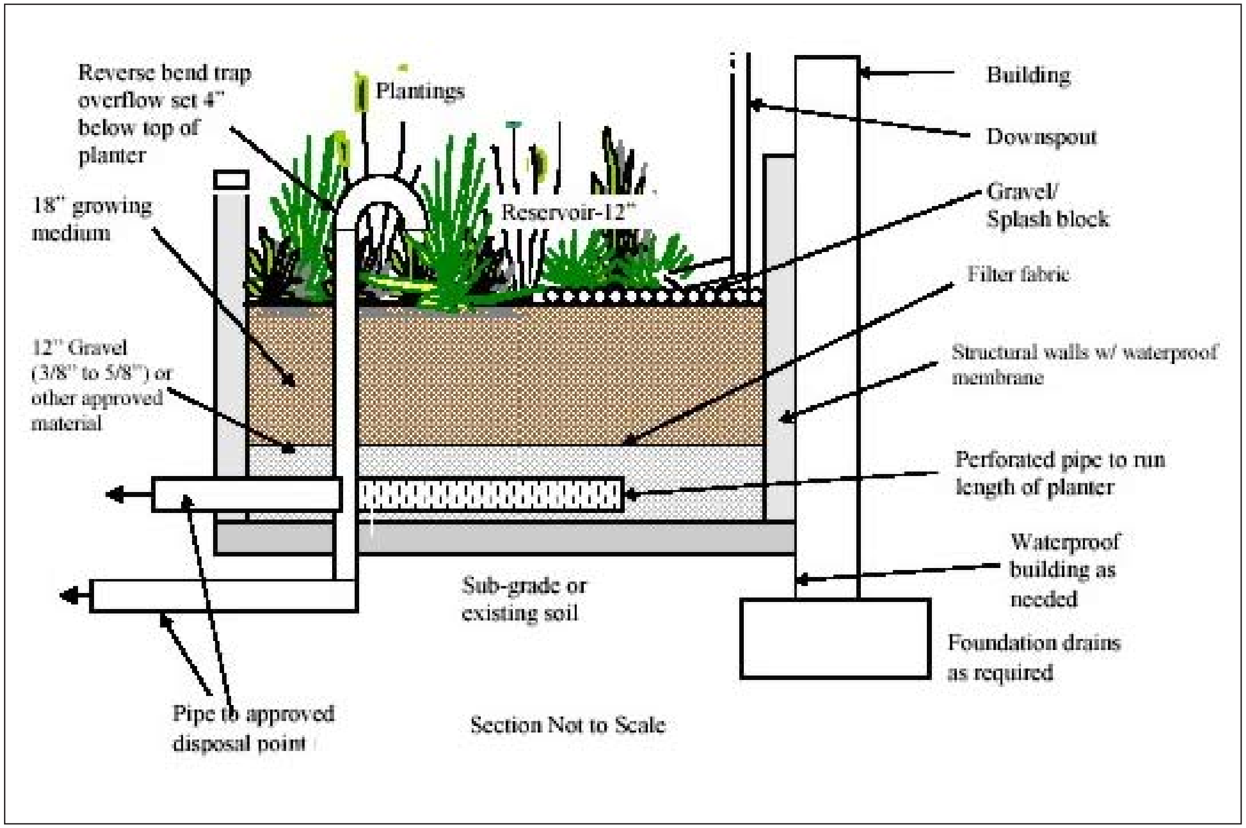

Figure 3: Flow-through Planter, *Source: City of Portland, Stormwater Management Manual, 2002*

$A_f = Vol*(d_f) / [k*(h_f + d_f)(t_f)]$

where:

- A_f = the required surface area (ft^2)
- Vol = the treatment volume (ft^3)
- d_f = depth of the soil medium (ft)
- k = the hydraulic conductivity (in ft/day, usually set at 4 ft/day, but can be varied depending on the properties of the soil media)
- h_f = average height of water above the planter bed (maximum 12 inches)
- t_f = the design time to filter the treatment volume through the filter media (usually set at 3 to 4 hours)

In addition, there are several physical geometry recommendations that should be considered in the layout and design of stormwater planters. The following design guidance is suggested:

- Minimum width: 1.5 feet (flow through planters) 2.5 feet (infiltration planters)
- Minimum length: none
- Maximum ponding depth: 12 inches
- Minimum building offset: 10 feet (applies to infiltration planters only)

Stormwater planters rely on successful plant communities to create the micro-environmental conditions necessary to replicate the functions of a forested eco-system. To do that, plant species need to be selected that are adaptable to the wet/dry conditions that will be present

Cost

Stormwater planters are cost-effective measures designed to help meet many of the management objectives of watershed protection. An example cost estimate for a proprietary flow-through-system is approximately $24,000 per acre of impervious surface (LID). Annual maintenance cost is approximately 2% to 8% of the system cost or in the range of $200 to $2,000 per impervious acre treated.

Maintenance

Inspections are an integral part of system maintenance. During the six months immediately after construction, planters should be inspected at least twice, and following precipitation events of at least 0.5 inches to ensure that the system is functioning properly. Thereafter, inspections should be conducted on an annual basis and after storm events of greater than or equal to the 1-year precipitation event (approximately 2.6 inches in Rhode Island). Minor soil erosion gullies should be repaired when they occur. Pruning or replacement of woody vegetation should occur when dead or dying vegetation is observed. Herbaceous perennials should be divided when over-crowding is observed, or approximately once every 3 years.

Figure 4: Photo of an Infiltration Planter
Source: City of Portland, Stormwater Management Manual, 2002

References

City of Portland, 2002. "Stormwater Management Manual". Environmental Services, Clean River Works.

Low Impact Development Center, Inc. (LID) http://www.lid-stormwater.net/intro/sitemap.htm#permpavers

Permeable Paving

Introduction

Permeable paving is a broadly defined group of pervious types of pavements used for roads, parking, sidewalks and plaza surfaces. It is designed to infiltrate stormwater runoff through its surface, thereby reducing runoff from a site. In addition, permeable paving reduces impacts of impervious cover by infiltrating more precipitation, augmenting the recharge of groundwater, and enhancing pollutant uptake removal in the underlying soils. Due to the potential high risk of clogging the underlying soils, which would minimize recharge and pollutant removal, the use of permeable paving is restricted in its use.

There are many different types of permeable paving, for example:

- Concrete grid pavers
- Lattice style paving that includes grass in spaces in between lattice work
- Porous pavement that looks like regular pavement (asphalt or concrete) but is manufactured without "fine" materials
- Cobblestone
- Brick
- Plastic modular blocks
- Crushed aggregate or gravel


Figure 1: Examples of Different Types of Permeable Paving, *Source: City of Portland, Stormwater Management Manual, 2002*

Facility Application

The ideal application for permeable paving is to treat low traffic roads (i.e. a few houses or a small cul-de-sac), overflow parking areas, sidewalks, plazas and courtyard areas. Permeable paving is intended to capture and manage small frequent rainfall events. These events can add up to as much as 30 – 50% of annual precipitation (Schueler, 1987). The system does not readily work for storms greater than 1-inch or with high rainfall intensities. The practice can be applied to manage almost every land use type from very dense urban areas to more rural residential areas. Major limitations to this practice are suitability of the grades, subsoils, drainage characteristics, and groundwater conditions.

For plazas and courtyard areas, vegetated infiltration trenches ("rain gardens") can also be used. These are primarily a gravel or sand base for infiltration with selected planting materials for aesthetics and some nutrient uptake. Like all other permeable paving types, the same limitations apply to this practice.

Benefits

Permeable paving can have many benefits when applied to redevelopment and infill projects in urban centers. The most notable benefits include:

- Groundwater recharge augmentation;
- Effective pollutant treatment for solids, metals, nutrients and hydrocarbons (see pollutant removal performance, Table 1);
- Aesthetic improvement to otherwise hard urban surfaces (lattice pavers);

Two long-term monitoring studies conducted in Rockville, MD, and Prince William, VA indicated high removal efficiencies for sediments, nutrients, metals and chemical oxygen demand. (Table 1)

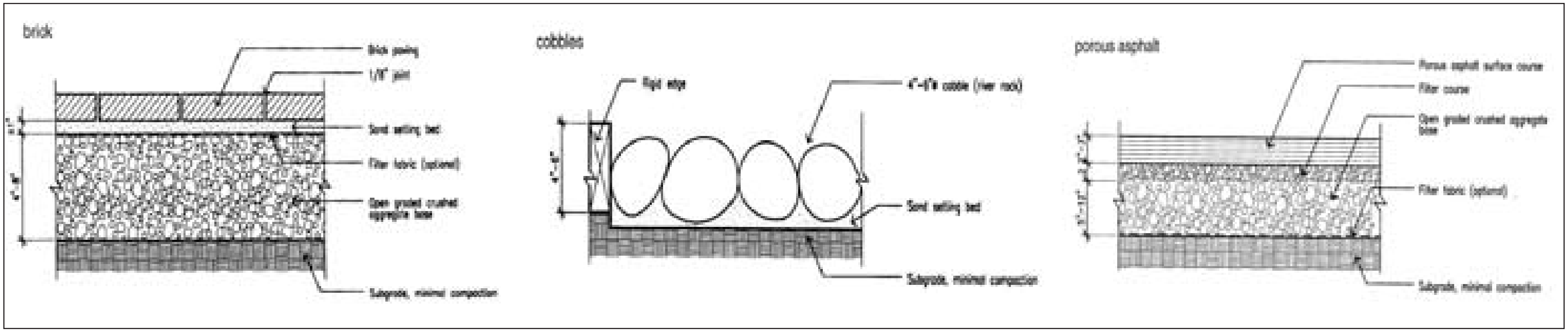

Figure 2: Cross Sections of Different Types of Permeable Paving, *Source: City of Portland, Stormwater Management Manual, 2002*

Table 1: Estimated Pollutant Removal Performance of Permeable Paving (Porous Pavement) (EPA, 1999)

Long Term Monitoring Conducted in Rockville, MD and Prince William, VA	
Pollutant Parameter	**% Removal**
Total Phosphorus	65
Total Nitrogen	80 – 85
Total Suspended Solids	82 – 95

Key factors to maintain effective pollutant removal include:

- Routine vacuum sweeping and high-pressure washing (with proper disposal of removed material)
- Drainage time of at least 24 hours
- Highly permeable soils
- Pretreatment of runoff from site
- Organic matter in subsoils
- Clean-washed aggregate

Limitations

Proper site selection is an important criteria in determining the failure rate of this practice. Areas with high amounts of sediment particles and high traffic volume (most roadways) are likely causes of system failure. Other areas not recommended for this practice include: high volume parking lots, high dust areas, and areas with wash-on from upland sources.

In addition to the relatively strict site constraints, a major limitation of this practice is the failure rate experienced in the field. A majority of failures in the past have been due to partial or total clogging of the paving with sediments or oil, during construction and over the life of the pavement. The clogging problem can be overcome by designing suitable measures to ensure that the paving:

- Does not receive runoff from areas that are likely to contribute sediment and debris.
- Is not constructed adjacent to areas subject to significant wind erosion.
- Is carefully protected from sediment inputs during the construction phase.
- Does not receive high vehicular traffic volumes and regular use by heavy vehicles (leading to subsoil compaction and reducing infiltration capacity).
- Receives pre-treated runoff through the placement and design of vegetated filter strips, where possible.

Like any stormwater infiltration practice, there is always a possibility of groundwater contamination. Permeable paving should not be used to manage hotspot land uses. Stormwater hotspots are areas where land uses or activities generate highly contaminated runoff. These areas include: commercial nurseries, any sort of auto recycling, repair, fleet washing facilities, fueling stations, commercial parking lots, and marinas.

Sizing and Design Guidance

Permeable paving areas are usually designed to accommodate a design storm of 1-inch. Storms greater than that will either sheet flow off the site, or if not graded properly, will pond on the site. Potential permeable paving sites need to be evaluated for the following criteria:

- Soils need to have a permeability between 0.5 and 3.0 inches per hour (up to 8.3 inches for sand).
- The bottom of the stone reservoir should not exceed a slope of 5 percent. Ideally it should be completely flat so that the infiltrated runoff will be able to infiltrate through the entire surface.
- Permeable paving should be located at least 2 feet above the seasonally high groundwater table, and at least 100 feet away from drinking water wells.
- Permeable paving should be located in low traffic and overflow parking areas.
- The contributing drainage area should be less than 15 acres.

Infiltration practices shall be designed to exfiltrate the water quality volume through the floor of each practice.

Calculate the surface area of infiltration trenches as:

$$A_p = V_w / (nd_t + fT/12)$$

where:

A_p = surface area (f^2)
V_w = design volume (e.g., WQ_v) (ft^3)
n = porosity (assume 0.4)
d_t = trench depth (maximum of seven feet, and separated by at least three feet from seasonally high groundwater) (ft)
f_c = infiltration rate (in/hr)
T = time to fill trench or dry well (hours) (generally assumed to be less than 2 hours)

Cost

Costs for permeable paving are significantly more than traditional pavement (Table 2). However, incorporating savings from not having to build a separate stormwater infrastructure in addition to paving, the overall project costs are reduced.

The estimated annual maintenance cost for a porous pavement parking lot is $200 per acre per year (EPA, 1999). This cost assumes four inspections each year with appropriate jet hosing and vacuum sweeping.

Maintenance

Depending on the type of permeable paving and the location of the site, the maintenance level ranges from high to low. Areas that receive high volume of sediment particles will clog more readily due to soil compaction. Concrete grid pavers and plastic modular blocks require less maintenance because they are not clogged by sediment as easily as porous asphalt pavement. However, regardless of the type of pavers used, the level of maintenance and ultimately the failure rate is dependent on the location of the site. Properly selected sites with permeable paving normally require regular vacuum sweeping or high pressure hosing once every three months to remove sediments. Typical maintenance activities for porous pavement are summarized below (Table 3).

Table 2: Cost Guides for Permeable Pavement System (LID)

Paver System	Cost Per Square Foot (Installed)
Asphalt	$0.50 to $1.00
Porous Concrete	$2.00 to $6.50
Grass/gravel pavers	$1.50 to $5.75
Interlocking Concrete Paving Blocks	$5.00 to $10.00

Table 3: Typical Maintenance Activities for Porous Pavement (WMI, 1997)

Activity	Schedule
Ensure that paving area is clean of debris	Monthly
Ensure that paving dewaters between storms	Monthly
Ensure that the area is clean of sediments	Monthly
Mow upland and adjacent areas, and seed bare areas	As needed
Vacuum sweep frequently to keep surface free of sediments (Typically 3 to 4 times a year)	As needed
Inspect the surface for deterioration or spalling	Annual

References

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Open Channels

Introduction

Open channels are concave, vegetated conveyance systems that can improve water quality through infiltration and filtering. When designed properly, they can be used to retain and pre-treat stormwater runoff. There are four different categories of open channels used in stormwater management practices. These include: drainage channels, grass channels ("biofilters"), dry swales and wet swales (Figure 1-A & 1-B).

Drainage channels have minimal or no stormwater pre-treatment capabilities. They are designed primarily to transport stormwater on the land surface. Grass channels are modified drainage channels that provide water quality treatment for the small, frequent storm events. The flow rate is the principle design criteria for grass channels ("rate-based" system). Dry swales have the same principle pre-treatment process as bioretention filters (see section on bioretention, page 86) which combines physical filtering and adsorption with bio-geochemical processes to remove pollutants. Dry swales are designed to rapidly dewater through a highly permeable layer and then collected by an underdrain pipe. Wet swales act as long, linear shallow wetland treatment systems. Wet swales occur when the water table is located very close to the surface. Dry/Wet swales are designed to treat or retain stormwater for a 24-hour period ("volume-based" systems).

Figure 1-A (above and far right): Photos of Different Open Channel Systems
(Source: City of Portland, Stormwater Management Manual, 2002)

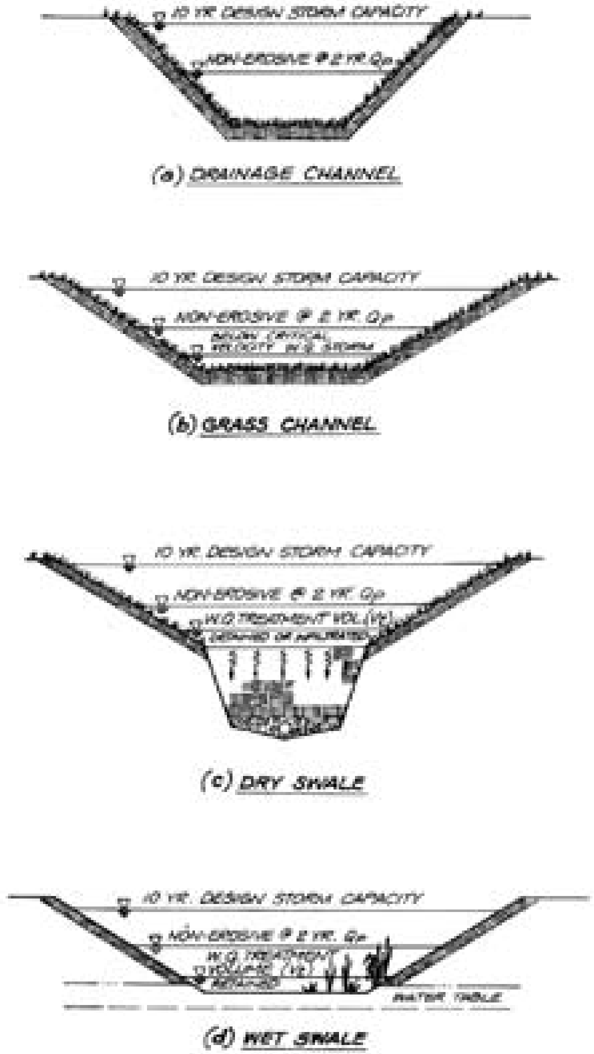


Figure 1-B: Schematic of Different Open Channel Systems
Source: Claytor & Schueler, 1996

Facility Application

Grass channels and dry/wet swales are rarely used to manage large storms or to provide peak flow attenuation for the so-called "channel forming" storms (i.e, in the range of the 1-year to 1.5-year frequency return interval), or flood control events (i.e., 10-year to 100-year frequency return intervals).

Grassed channels accent the natural landscape, break up impervious areas, and are appropriate alternatives to curb and gutter systems (Figure 2). They are best suited to treat runoff from rural or very low density areas and major roadway and highway systems. They are often used in combination with other stormwater management practices to provide pre-treatment and attenuation, but can be used as stand-alone practices. The design objective for grass channels is to maintain a low flow rate in order to achieve a minimum residence time of ten minutes. A key factor in the suitability of grass channels designed for infiltration is the on-site soils characteristics. Grass channels have the same design criteria as applied to infiltration basins and trenches: soil type, infiltration rate and separation to groundwater and bedrock.

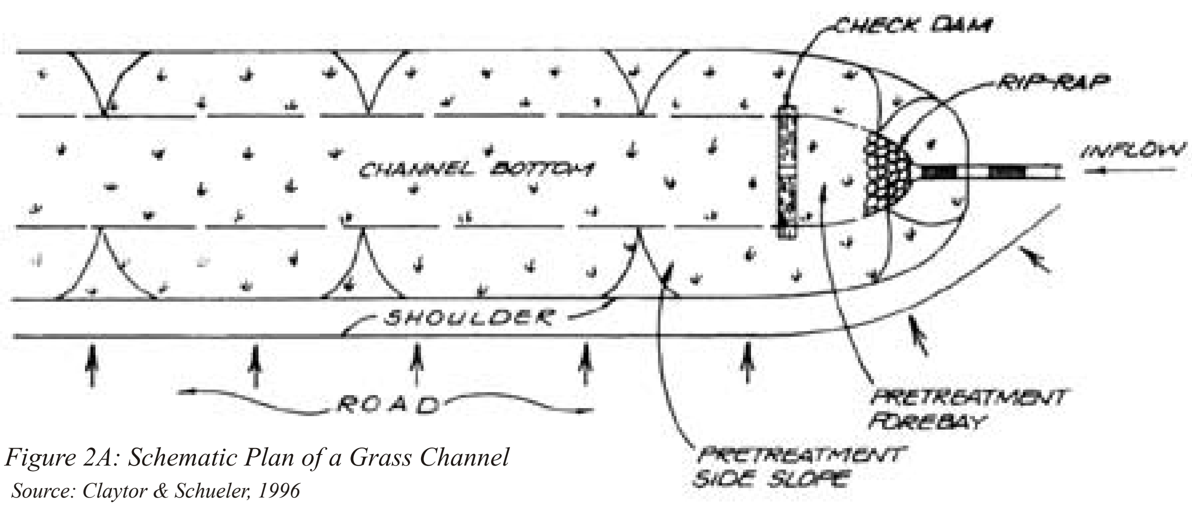


Figure 2A: Schematic Plan of a Grass Channel
Source: Claytor & Schueler, 1996

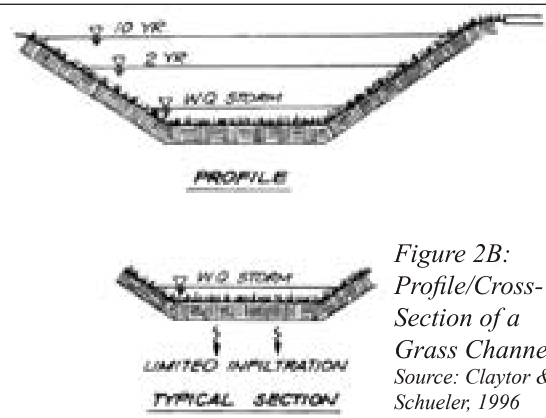


Figure 2B: Profile/Cross-Section of a Grass Channel
Source: Claytor & Schueler, 1996

Source: Claytor

Figure 3-A (above and far right): Photos of Dry Swales
Source: Claytor

Dry swales are appropriate in areas where standing water are not desirable such as residential, commercial, industrial areas and highway medians. In dry swales, a prepared soil bed is designed to filter the runoff for water quality (Figure 3). Runoff is then collected in an underdrain system and is discharged to the downstream drainage system. The design objective for dry swales is to drain down between storm events within twenty-four hours.

Wet swales are similar to stormwater wetlands in their use of wetland vegetation to treat stormwater runoff (Figure 4). The water

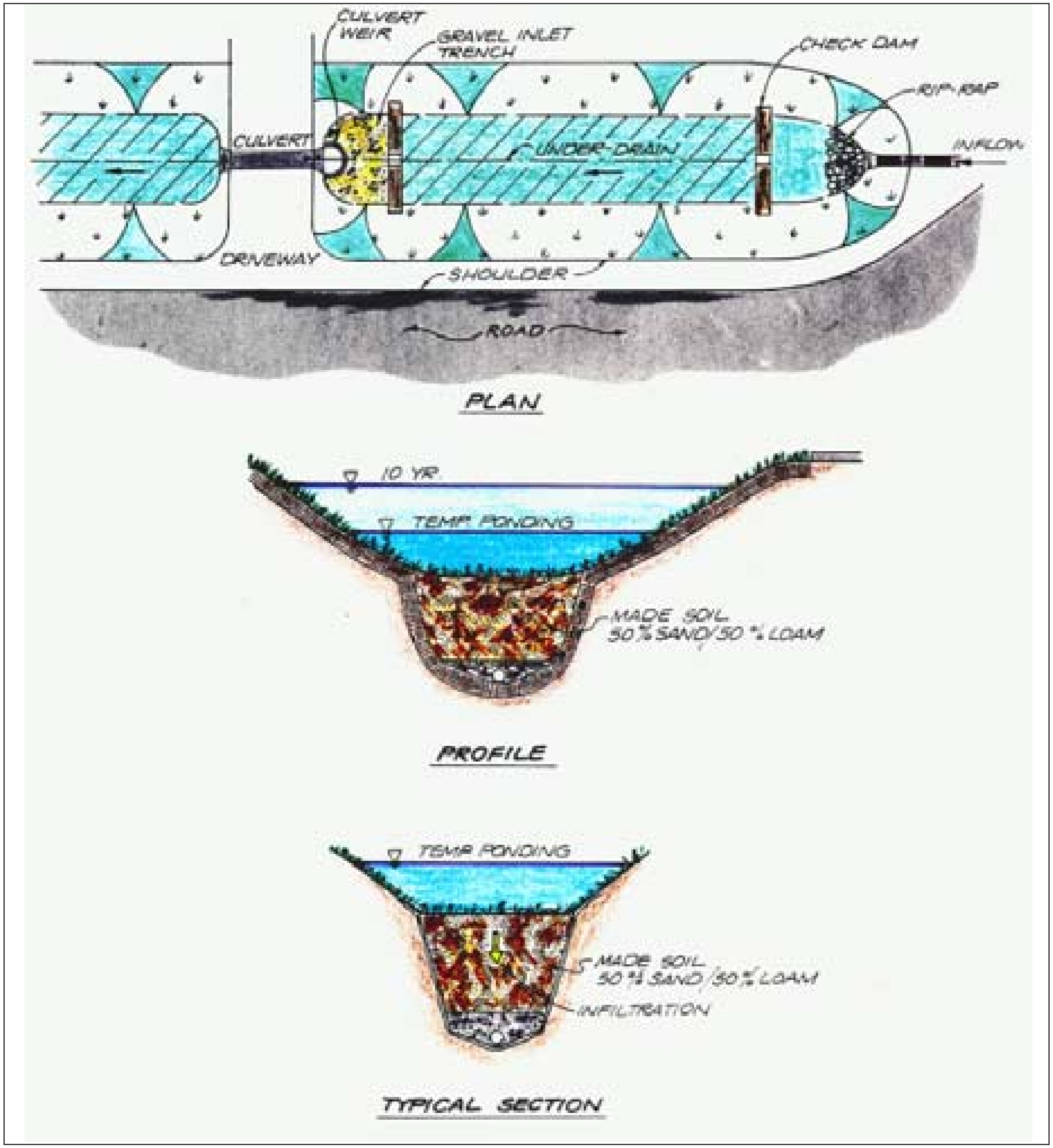


Figure 3-B: Plan and Section of Dry Swale, *Source: Claytor & Schueler, 1996*

quality treatment mechanism relies primarily on settling of suspended solids, adsorption, and uptake of pollutants by vegetative root systems (Claytor & Schueler, 1996). Wet swales are designed to retain runoff for 24 hours. The application of wet swales are limited due to standing water and the potential problems associated with it such as safety hazards, odor, and mosquitoes.

The feasibility of installing any open channel on a site depends on the local climate, the right soils to permit the establishment and maintenance of a dense vegetative cover, and available area. The contributing area, slope,

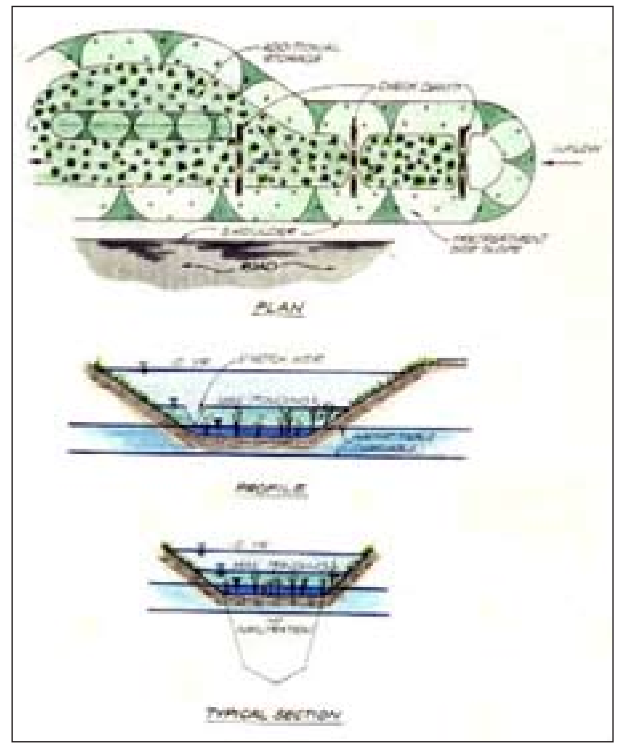


Figure 4: Schematic and Photo of a Wet Swale
Source: Claytor & Schueler, 1996

and perviousness of the site will determine the dimension and slope of the open channels.

Benefits

The benefits of open channel systems include minimized water balance disruptions through the reduction of peak flows, the filtering and adsorption of pollutants, and increased recharge. Other benefits include lower capital cost relative to a more structural stormwater management practices, more aesthetically pleasing because they accent the natural landscape and break up impervious areas, and a net benefit to the public in the reduction of urban heat island effect.

Source: Claytor

Table 1: Estimated Pollutant Removal Performance of Open Channels

	Grass Channel [1]	Dry Swale [2]	Wet Swale [2]
Pollutant Parameter	% Removal	% Removal	% Removal
Total Phosphorus	**9**	**65**	**20**
Total Nitrogen	**NA**	**50**	**40**
Total Suspended Solids	**81**	**90**	**80**
Nitrate	**38**	**80**	**50**
Oxygen Demanding Substances	**67**	**NA**	**NA**
Hydrocarbons	**62**	**NA**	**NA**
Cadmium	**42**	**NA**	**NA**
Copper	**51**	**80 - 90**	**40-70**
Lead	**67**		
Zinc	**71**		

Note:
1 – United States Environmental Protection Agency, 1999
2 - Claytor and Schueler, 1996

Limitations

Open channels used in stormwater management are typically ineffective for water quality treatment and are vulnerable during large storm events. High velocity flows as a result of these large storm events can erode the vegetative cover, if the channels or swales are not designed properly. Other limitations include:

- Areas with very flat grades, steep topography, and wet or poorly drained soils.
- Wet swales are potential drowning hazards, mosquito breeding areas, and may emit odor.
- The land space required for open channels ranges from 6.5 percent of total contributing impervious area for grass channels and 10 to 20 percent for dry and wet swales (Claytor and Schuler, 1996).
- Pre-treatment is necessary to extend the practice's functional life, as well as to increase the pollutant removal capability. A shallow forebay at the initial inflow point is recommended as a pre-treatment component.

Sizing and Design Guidance

The general design of open channel systems should take into consideration the following criteria (also summarized in Table 2):

- **Soils** – for grass channels, the infiltrating capability is a factor in locating swales. Swale infiltration rates measured in the field should be between 0.5 and 5.0 inches per hour. Suitable soils include sand, sandy loam, loamy sand, loam and silty loam. Highly permeable soils provide little treatment capability and soils with low permeability do not provide adequate infiltration during the short retention time. The soil bed underneath the dry swale should consist of a moderately permeable soil material, with a high level of organic matter.

- **Shape** – Open channel systems are usually parabolic or trapezoidal in shape. Parabolic swales are natural and are less prone to meander under low flow conditions. Trapezoidal swales provide additional area for infiltration but may tend to meander at low flows and may revert to a parabolic form. Trapezoidal sections should be checked against the parabolic sizing equation as a long-term functional assessment.
- **Dimension** – for grass channels, the side slopes in the channel should be 3:1 or flatter. The longitudinal slope should be between 1 and 4 percent for grass channels and 1 and 2 percent for dry and wet swales. The minimum length of a grass channel to ensure water quality treatment is 600 feet. This is determined based on the maximum flow velocity of 1 foot per second (fps) for water quality treatment, multiplied by a minimum residence time of 10 minutes (600 seconds). The wet swale length, width, depth, and slope should be designed to temporarily accommodate the water quality volume through surface ponding. For a dry swale, all of the surface ponding should dissipate within a maximum 24-hour duration.
- **Vegetative Cover** – Dense vegetative cover slows the flow of water through the swale and increases treatment. Vegetation should be able to tolerate being wet for 24 hours. The velocities in the open channel systems should not exceed the erosive levels for the vegetative cover in the channel.

Once runoff rates and volumes are calculated using an appropriate hydrologic model, the basic equation for sizing open channel systems are summarized below (Table 3).

Table 2: Design Criteria for Open Channel Systems (Claytor and Schueler, 1996)

Parameter	Design Criteria	
	Grass Channel	**Dry and Wet Swale**
Bottom Width	2 feet minimum, 6 feet maximum	2 feet minimum, 8 feet maximum widths up to 16 feet are allowable if a dividing berm or structure is used
Side Slopes	3:1 (horizontal:vertical)	2:1 maximum, 3:1 or flatter preferred
Longitudinal Slope	1.0% minimum, 4.0% maximum	1.0% to 2.0% without check dams
Flow Depth and Capacity	4 inches for water quality treatment	Surface storage of water quality volume with a maximum depth of 18 inches for water quality treatment (12 inches average depth). Adequate capacity for 10 year storm with 6 inches of freeboard
Manning's n Value	0.15 for water quality treatment (depths ≤ 4 inches) varies from 0.15 to 0.03 for depth between 4 and 12 inches and 0.03 minimum for depths ≥12 inches	
Flow Velocity	1.0 fps for water quality treatment 4.0 fps to 5.0 fps for 2 year storm 7.0 fps for 10 year storm	4.0 fps to 5.0 fps for 2 year storm
Length	Length necessary for 10 minute residence time	Length necessary to drain (dry swale) and retain (wet swale) runoff for 24 hours

Cost

Open channel systems are cost-effective measures relative to curb and gutter systems and underground storm sewers. The base cost for grass channels is 25 cents per square foot (SWRPC, 1991). Designed swales, such as a dry swale with prepared soil and underdrain piping has an estimated cost of $4.25 per cubic foot (SWRPC, 1991). Relative to other filtering system options, these costs are considered to be moderate to low. Most recent cost estimates have approximated $5 per linear feet for grass channels and $19 per linear feet for dry swales. The annual maintenance cost can range from 5 to 7 percent of the construction cost (SWRPC, 1991).

Table 3: Design Equations for Open Channel Systems

Grass Channel		Dry Swales		Wet Swales	
Equation		**Equation**		**Equation**	
$V = (1.49/n)R^{2/3} S^{1/2}$		$A_f = Vol*(d_f) / [k*(h_f + d_f)(t_f)]$		Vol = A x L	
R = A / P					
Variables		**Variables**		**Variables**	
V	Velocity, should be less than 1 ft/sec	A_f	Required surface area of the dry swale (ft^2)	Vol	Retention volume (ft^3)
n	Roughness coefficient (tabulated values)	Vol	Treatment volume (ft^3)	A	Cross sectional area (ft^2)
R	Hydraulic radius (ft)	d_f	Depth of the filter medium (ft)	L	Length of swale (ft)
A	Cross sectional area (ft^2)	k	Hydraulic conductivity (ft/day)		
P	Wetted perimeter (ft)	h_f	Average height of water above the bottom of dry swale (ft)		
S	Longitudinal slope	t_f	Design time to filter the treatment volume through the filter media (usually set at 24 hours)		

Maintenance

The life of an open channel system is directly proportional to its maintenance frequency. The maintenance objective for this practice includes keeping up the hydraulic and removal efficiency of the channel and maintaining a dense, healthy grass cover. The following activities are recommended on an annual basis or as needed:

- Mowing and litter and debris removal
- Stabilization of eroded side slopes and bottom
- Nutrient and pesticide use management
- Dethatching swale bottom and removal of thatching
- Discing or aeration of swale bottom

Every five years,the channel bottom may need reshaping and removal of sediment to restore original cross section and infiltration rate, and seeding or sodding to restore ground cover is recommended.

Maintenance for the grass channel consists of annual inspections and correction of erosion gullying and reseeding as necessary. When sediment accumulates to a depth of approximately 3 inches, it should be removed and the swale should be reconfigured to its original dimensions. The grass in the swale should be mowed at least 4 times during the growing season. The condition of the grass vegetation should be noted during inspection and repaired as necessary.

Dry Swales should be inspected on an annual basis and just after storms of greater than or equal to the 1-year frequency storm . Both the structural and vegetative components should be inspected and repaired. When sediment accumulates to a depth of approximately 3 inches, it should be removed and the swale should be reconfigured to its original dimensions. The grass in the dry swale should be mowed at least 4 times during the growing season. If the surface of the dry swale becomes clogged to the point that standing water is observed in the surface 48 hours after precipitation events, the bottom should be roto-tilled or cultivated to break up any hard-packed sediment, and then reseeded. Trash and debris should be removed and properly disposed of.

Wet swales should be inspected annually and after storms of greater than or equal to 2.8 inches of precipitation. During inspection, the structural components of the pond, including trash racks, valves, pipes and spillway structures, should be checked for proper function. Any clogged openings should be cleaned out and repairs should be made where necessary. The embankments should be checked for stability and any burrowing animals should be removed. Vegetation along the embankments, access road, and benches should be mowed annually. Woody vegetation along those surfaces should be pruned where dead or dying branches are observed, and reinforcement plantings should be planted if less than 50 percent of the original vegetation establishes after two years. Sediment should be removed from the bottom of the swale.

References

Claytor and Schueler, 1996. Design of Stormwater Filtering Systems. for the Chesapeake Research Consortium. Center for Watershed Protection, Ellicott City, Maryland. 179 pp.

United States Environmental Protection Agency, "Storm Water Technology Fact Sheet, Vegetated Swales", September 1999.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. Costs of Urban Nonpoint Source Water Pollution Control Measures. Waukesha, WI.

Stream Daylighting

Introduction

Stream daylighting involves uncovering a stream or a section of a stream that had been artificially enclosed in the past to accommodate development. The original enclosure of rivers and streams often took place in urbanized areas through the use of large culvert operations that often integrated the storm sewer system and combined sewer overflows (CSO's). The daylighting operation, therefore often requires overhauls or updating of storm drain systems and re-establishing stream banks where culverts once existed. When the operation is complete, what was once a linear pipe of heavily polluted water can become a meandering stream with dramatic improvements to both aesthetic and water quality. In some cases, instead of creating a natural channel for the daylighted stream, the culvert is simply replaced with a concrete channel.

Aside from water quality and general aesthetic improvements, stream daylighting can play an integral role in neighborhood restoration and site redevelopment efforts. Aside from improvements to infrastructure, stream daylighting can restore floodplain and aquatic habitat areas, reduce runoff velocities and be integrated into pedestrian walkway or bike path design.

Applicability of Practice

Stream daylighting can generally be applied most successfully to sites with considerable open or otherwise vacant space. This space is required to: 1) Potentially reposition the stream in its natural stream bed; 2) Accommodate the meandering that will be required if a natural channel is being designed; and 3) Provide adjacent floodplain area to store water in large storm flow situations. However, where a concrete channel will replace a culverted stream, these projects require significantly less space than those designed for a natural streambed.

Benefits

Performance data for stream daylighting are poorly documented in general, owing in large part to the fact that many of the objectives involved with daylighting are difficult to quantify. The aesthetic improvements provided by daylighted streams can be expected to add appeal to neighborhoods or urban areas, but exactly how this appeal adds to property values or general economic development is an elusive exercise. Despite the lack of hard economic data associated with these efforts, successful operations have documented significant increases in pedestrian traffic and general public use.

With regard to water quality data, again, hard data are difficult to find relative to pollution attenuation. Where CSO separation and other upgrades to storm sewer systems are part of a daylighting project, significant water quality improvements can be expected during wet weather events. Also, as ultraviolet radiation is one of the most effective ways to eliminate pathogens in surface water, exposing these streams to sunlight could significantly decrease pathogen counts in the surface water.

Limitations

The primary limitations of stream daylighting include the high costs associated with these projects, the highly technical aspects of the stream restoration process, and high levels of maintenance required in the early years of implementation. Collectively, these factors can overwhelm local planning efforts and create levels of inertia that are difficult to overcome. Planning efforts toward stream daylighting must therefore be well-funded, highly organized, and success will often depend on quality leadership within a community.

Sizing and Design Considerations

As with many other considerations relative to stream daylighting, sizing new stream channels and designing for flood storage and construction are very site-specific considerations. From a planning perspective, however, there are several considerations that can serve as a checklist in the earliest stages of design (Pinkham, 2000).

1) The restoration team must consider to what extent existing infrastructure will serve as a barrier during the construction phase. Beyond the presence of antiquated storm sewer systems, sanitary sewer lines, gas and electric lines and other subsurface utilities could pose a significant challenge if not accounted for early in the design process.
2) The depth to groundwater and the types of soil are important considerations as high groundwater levels that were shut out by large culverts could reconnect to the stream and cause higher base flows than what is observed within the existing culvert. Also, the type of fill that was used when the culvert was installed may need to be excavated and disposed of before a new channel is established.
3) Planners and designers will have to consider to what extent sedimentation will be a problem in the new stream. The level to which sedimentation will occur and the manner in which it is introduced may call for the use of engineered BMPs such as forebays to be incorporated into the design of the new channel.
4) Also with regard to maintenance, designers will have to consider to what degree access will be necessary to the stream channel for maintenance. If trash management is anticipated to be an issue or if public safety concerns arise, designers may have to plan for both pedestrian and vehicular access to selected areas of the new channel.
5) Hydrologic engineering considerations are paramount when designing a new stream channel in order to avoid flooding and channel erosion for the life of the stream. Calculations must be conservative and account for extreme rain events as well as future development within the contributing area to the new stream.

Cost

Due to the highly variable nature of daylighting projects it is difficult to provide concrete unit costs for these endeavors. Depending on the length of the stream and the level of storm sewer improvement associated with a daylighting project, costs can range from the low thousands to the low millions. It is important to note, however, that costs for daylighting streams are often comparable to costs for replacing culverts. This fact should inspire planners to at least consider daylighting when an ordinary culvert replacement is scheduled. An excellent inventory of daylighting projects with associated costs is provided in *Daylighting, New Life for Buried Streams* published by the Rocky Mountain Institute in 2000. Other samples of comparative costs for bank restoration techniques are provided in *The Practice of Watershed Protection: Article 145* “Bioengineering in Four Mile Run, Virginia” (Scheuler, et al, 2000).

Maintenance

Maintenance of daylighted stream areas can be intensive during the first years the stream is established. Regular inspection of natural banks to ensure their integrity is essential. Further inspection of new vegetation is also important to ensure that plantings are progressing in a manner that will stabilize the new banks of the stream. Once stream banks are well established, regular maintenance is similar to that required in any public green space. Trash removal, mowing and general housekeeping represent the bulk of what can be expected once streams are well-established.

References

Pinkham, Richard. *Daylighting, New Life for Buried Streams*. Rocky Mountain Institute, 2000.

Scheuler, Thomas R.; Heather K. Holland, *The Practice of Watershed Protection*, “Article 145: Bioengineering in Four Mile Run, Virginia”, 2000.

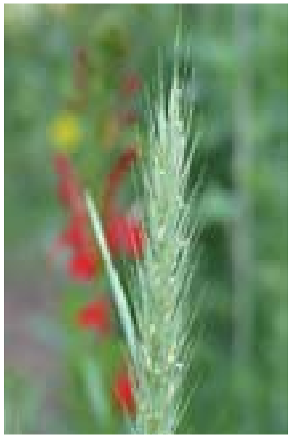
Vegetated Buffers

Introduction

Vegetated buffers refer to areas abutting surface water or wetland resources where vegetation serves as a buffer from stormwater runoff and other development-related impacts. Vegetated buffers can either be planted during the course of development, or existing vegetation can be preserved as part of the overall site design. Buffers with low-growing dense vegetation can serve as effective filters of several pollutants including metals, nutrients and pathogens. These areas also serve to disperse the flow of stormwater runoff, reduce runoff velocity and therefore serve to protect riparian areas from erosion. Where buffers include trees, these areas can enhance aquatic habitat through shading, and provide additional habitat for other terrestrial animals.

Establishing newly planted buffers should include the use of native vegetation to protect against ecological damage from invasive species. Lists of potential grasses, groundcovers, shrubs and trees are extensive. An excellent base reference when considering vegetation choices for buffers is *Sustainable Trees and Shrubs for Southern New England*, prepared by the University of Rhode Island, University of Massachusetts, and the United States Department of Agriculture, 1993.

Schizachyrium scoparium
(Little bluestem)



Elymus virginicus
(Vriginia wild rye)

Sorghastrum nutans
(Indian grass)

Panicum virgatum
(Switchgrass)

Cornus kousa "Snowboy"

Pinus strobus (White Pine)

Hamamelis intermedia

Carpinus caroliniana
American Hornbeam

Juniperus virginiana
Eastern Red Cedar

Quercus rubra (Red Oak)

Applicability of Practice

Vegetated buffers are potentially applicable to any site where surface water bodies or wetlands lie in close proximity to developed areas. Establishing new buffer areas affords the opportunity to choose vegetation suited to particular environmental objectives and/or pre-existing conditions. For example, where nutrient management is a high priority, specific plants and soil amendments can be used to enhance the nutrient uptake within the buffer area. Where pathogen management is more of a priority, a vegetative buffer can be designed as thick low-lying grasses that will optimally detain and filter stormwater as it passes through the buffer. Plant choice will also be guided by the amount of sunlight and water that will be received by the buffered area.

Benefits

Vegetated buffers serve as a natural landscape separation from areas of development to surface water resources. Whether forested or grassy in appearance, buffers provide a natural area that serves both to protect the water resource and provide varied level of pedestrian access. Although hard data are scarce regarding economic benefits, there is a general consensus that these green spaces enhance the value of properties where they are established.

Performance data for vegetated buffer strips have classically focused on pollutant removal capacity. Data have been reported primarily for attenuation of Total Suspended Solids (TSS), Nitrogen, Phosphorus and fecal coliform bacteria. Table 1 demonstrates the pollutant removal capacity of buffers at several different sites for TSS and nutrients. Fecal coliform bacteria attenuation has been monitored in agricultural applications where buffer strips generally consist of relatively small areas of grass plantings. Regardless of the size of these buffer strips, pathogen attenuation has repeatedly been recorded at levels over 80% (Coyne, et al., 1998).

Table 1. Pollutant Removal Rates (%) in Buffer Zones

Reference	Buffer Vegetation	Buffer Width (meters)	Pollutant		
			TSS	TP	TN
Dillaha *et al*.1989	Grass	4.6	63	57	50
		9.1	78	74	67
Magette *et al*. 1987	Grass	4.6	72	41	17
		9.2	86	53	51
Schwer and Clausen 1989	Grass	26	89	78	76
Lowrance *et al*. 1983	Native hardwood forest	20 - 40	-	23	-
Doyle *et al*. 1977	Grass	1.5	-	8	57
Barker and Young 1984	Grass	79	-	-	99
Lowrance *et al*. 1984	Forested	-	-	30-42	85
Overman and Schanze 1985	Grass	-	81	39	67
Young *et al*. 1980	Grass	27.4	-	88	87

Source: Aquatic Buffers Fact Sheet: Buffer Zones www.stormwatercenter.net

The removal capacity of any given buffered area is affected by the volume of stormwater being received, the width of the buffer strip, the slope of the buffer as it leads to the receiving water, and the type of vegetation. In grassed or meadow applications, establishing new buffer areas can happen quickly, and notable results will occur within two years of the project outset. For areas using mature trees as part of the buffering strategy, a mix of young trees and low-lying vegetation should be used at the outset to ensure a healthy buffer appearance and a notable level of protection in the early years of implementation.

Limitations

Vegetated buffers have few limitations depending on the overall design and the goals for implementation. In cases where a mature forest is the final goal, proponents may be limited by the amount of available space along a river or stream. Also adequate human resources must be available, particularly in the first years of implementation to ensure that plantings receive proper watering and nutrients.

Sizing and Design Considerations

Because of the wide variety of potential designs for vegetated buffer areas, it is more useful to discuss general tenets of design rather than specific engineering specifications. Perhaps the best available summary of stream buffer design consideration comes from the Stormwater Manager's Resource Center (SMRC) website. The following figure and table were taken from this website and provide a general schematic of a forested buffer area as well as a summary of design considerations for any style of buffer zone.

Relative Cost

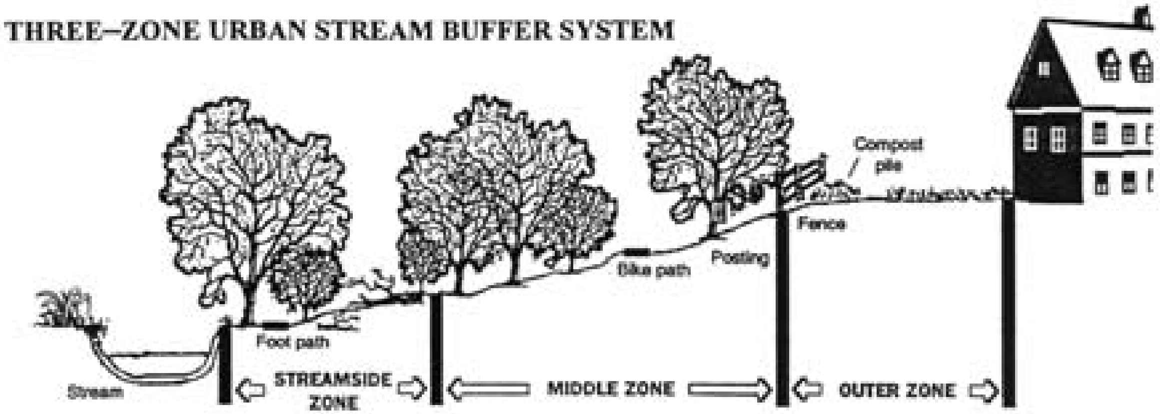
Costs for establishing vegetative buffers will vary dramatically depending on the type of vegetation chosen and the extent to which existing buffers will simply be maintained. Grass seed for drought tolerant species or wildflower mixes will generally cost between $300 and $600 per acre of newly established buffer. If a mature forest is the desired goal for a newly established buffer, trees will cost between $125 to $300 each depending on the type and caliper (tree whips can be purchased for as little as $2-3 from conservation agencies). If clearing and grubbing are required for the initial grow-in of vegetated areas, a cost estimate of $12 per square foot is a reasonable expectation.

Studies have shown that establishing vegetated buffers adds value to adjacent properties and it is therefore reasonable for a property owner to expect a return on investments to these areas (Scheuler, et al. 2000).

Maintenance

Maintenance of buffer areas depends in large part on the type of buffer that is established. For all buffered areas, however, a moderate amount of trash pick-up and general housekeeping is expected depending on the level of pedestrian traffic. If buffered areas are more intensely landscaped or contain engineered features such as swales or depressions, these areas may require mowing, pruning and regular inspection after rainfall to ensure upkeep and integrity. However, simple drought tolerant buffers require little maintenance beyond periodic housekeeping.

THE THREE–ZONE URBAN STREAM BUFFER SYSTEM



CHARACTERISTICS	STREAMSIDE ZONE	MIDDLE ZONE	OUTER ZONE
FUNCTION	Protect the physical integrity of the stream ecosystem	Provide distance between upland development and streamside zone	Prevent encroachment and filter backyard runoff
WIDTH	Min. 25 feet, plus wetlands and critical habitats	50 to 100 feet, depending on stream order, slope, and 100 year floodplain	25 foot minimum setback to structures
VEGETATIVE TARGET	Undisturbed mature forest. Reforest if grass	Managed forest, some clearing allowable	Forest encouraged, but usually turfgrass
ALLOWABLE USES	*Very Restricted* e.g., flood control, utility right of ways, footpaths, etc.	*Restricted* e.g., some recreational uses, some stormwater BMPs, bike paths, tree removal by permit	*Unrestricted* e.g., residential uses including lawn, garden, compost, yard wastes, most stormwater BMPs

Source: Schueler, 1995

Table 2. Factors Affecting Buffer Pollutant Removal Performance	
Factors that Enhance Performance	**Factors that Reduce Performance**
Slopes less than 5%	Slopes greater than 5%
Contributing flow lengths < 150 ft.	Overland flow paths over 300 feet
Water table close to surface	Groundwater far below surface
Check dams/ level spreaders	Contact times less than 5 minutes
Permeable, but not sandy soils	Compacted soils
Growing season	Non-growing season
Long length of buffer or swale	Buffers less than 10 feet
Organic matter, humus, or mulch layer	Snowmelt conditions, ice cover
Small runoff events	Runoff events > 2 year event.
Entry runoff velocity less than 1.5 ft/sec	Entry runoff velocity more than 5 ft/sec
Swales that are routinely mowed	Sediment buildup at top of swale
Poorly drained soils, deep roots	Trees with shallow root systems
Dense grass cover, six inches tall	Tall grass, sparse vegetative cover

Source: Aquatic Buffers Fact Sheet: Buffer Zones **www.stormwatercenter.net**

References

Coyne, M.S.; R.A. Gilfillen; A. Villalba; Z. Zhang; R. Rhodes; L. Dunn; R.L. Blevins. "Fecal bacteria Trapping by Grass Filter Strips during Simulated Rain", Journal of Soil and Water Conservation, Summer 1998 v53 n2 p140(6).

Scheuler, Thomas R.; Heather K. Holland, *The Practice of Watershed Protection*, "Article 39: The Architecture of Urban Stream Buffers", 2000.

Seed mixes are available for a variety of sites and soil conditions. Top left: Erosion Control/ Restoration Mix for Dry Sites. Top right: New England Conservation/ Wildlife Mix with Wildflower Mix. Bottom left: New England Erosion Control/Restoration Mix for Dry Sites. Bottom right: New England Native Warm Season Grass Mix. These examples, among others are distributed by New England Wetland Plants, Inc. Photos Courtesy of New England Environmental, Inc.

Stormwater Wetlands

Introduction

Stormwater wetlands are excavated basins with irregular perimeters and undulating bottom contours into which wetland vegetation is strategically placed to enhance pollutant removal from stormwater runoff. The constructed wetland system used in stormwater management practices are designed to maximize the removal of pollutants from stormwater runoff via several mechanisms: microbial breakdown of pollutants, plant uptake, retention, settling, and adsorption.

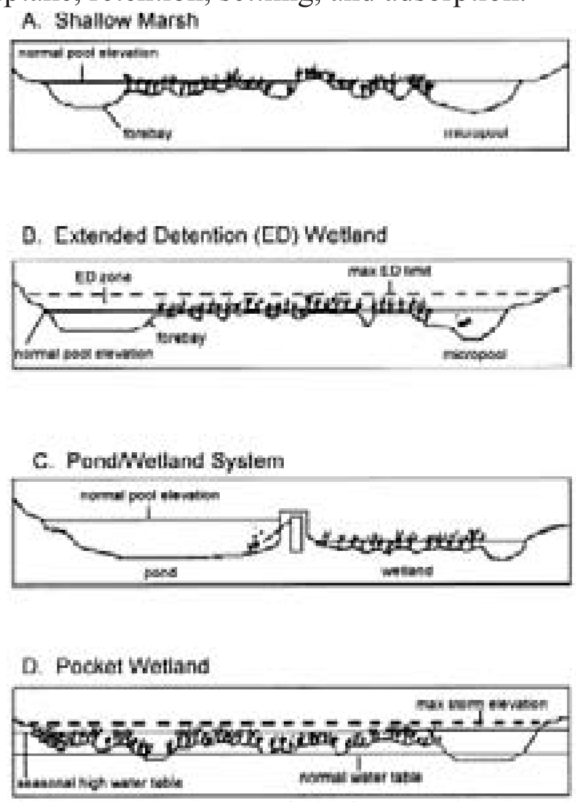


Figure 1: Comparative Profiles of Stormwater Wetlands
Source: Schueler, 1992

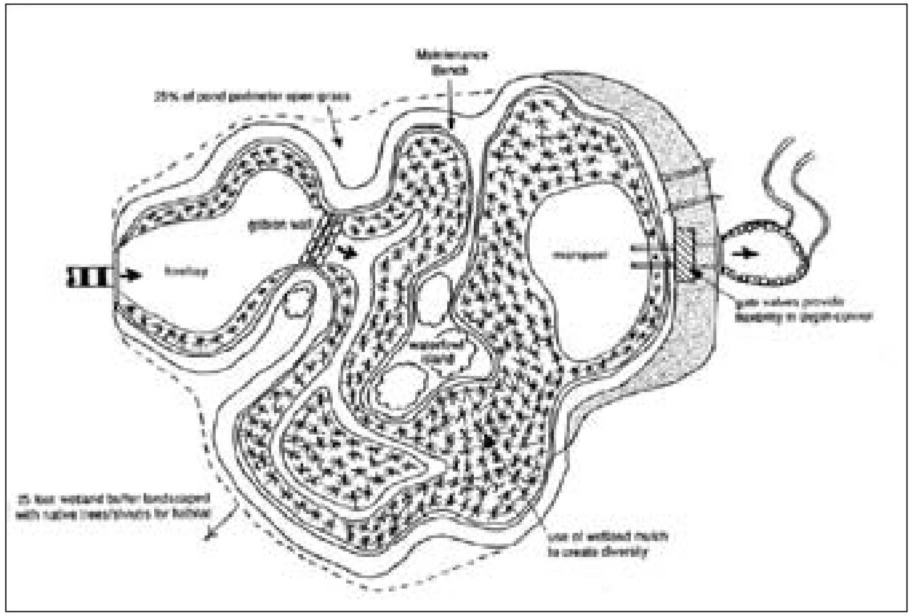


Figure 2: Shallow Marsh System, *Source: Schueler, 1992*

There are four basic designs of free water surface constructed wetlands: shallow marsh, extended detention wetland, pond/wetland system, and pocket wetland. These wetlands (except pocket wetland) store runoff in a shallow basin (Figure 1) and are used to provide channel erosion control storage as well as flood attenuation. Pocket wetlands are only generally used to provide water quality treatment.

Facility Application

Stormwater wetlands require relatively large contributing drainage areas and/or sufficient baseflow to maintain water within the wetland. Typically, stormwater wetlands will not have the full range of ecological functions of natural wetlands. They are designed specifically for flood control and water quality treatment purposes. Stormwater wetlands should not be located within existing jurisdictional wetlands. In some isolated cases, a permit may be granted to convert an existing degraded wetland in the context of local watershed restoration.

The use of stormwater wetlands is limited to various site constraints, soil types, depth to groundwater, contributing drainage area, and available land area. Medium-fine texture soils (such as loams and silt loams) are best to establish vegetation, retain surface water, permit groundwater discharge, and capture pollutants (Metropolitan Council, 2001). In areas where infiltration is too rapid to sustain permanent soil saturation, an impermeable liner may be required.

Shallow marsh design requires the most land of the four potential designs and a sufficient baseflow to maintain water within the wetland. Stormwater enters through a forebay where the larger solids and course organic material settle out. The stormwater discharged from the forebay passes through emergent vegetation, which filters organic materials and soluble nutrients (Figure 2). An extended detention wetland is a modified shallow marsh system used to store water above the normal pool elevation (Figure 3). This wetland attenuates flows and relieves downstream flooding.

A pond/wetland system has a wet pond and a shallow marsh area (Figure 4). The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland. Less land is required for a pond/wetland system than for the shallow marsh system.

Pocket wetlands require the least amount of land space relative to other constructed wetland, and therefore may be appropriate for smaller sites (Figure 5). This wetland is generally used for water quality treatment only and does not provide channel protection and extreme flood attenuation.

Benefits

Stormwater wetlands have many benefits when applied to redevelopment and infill projects in urban centers. The most notable benefits include:

- Improvements in downstream water quality
- Settlement of particulate pollutants
- Reduction of oxygen-demanding substances and bacteria from urban runoff
- Biological uptake of pollutants by wetland plants
- Flood attenuation
- Reduction of peak discharges
- Enhancement of vegetation diversity and wildlife habitat in urban areas
- Aesthetic enhancement and valuable addition to community green space
- Relatively low maintenance costs

Properly constructed and maintained wetlands can provide very high removal rates of pollutants from stormwater. Table 1 summarizes the removal efficiency for certain pollutants.

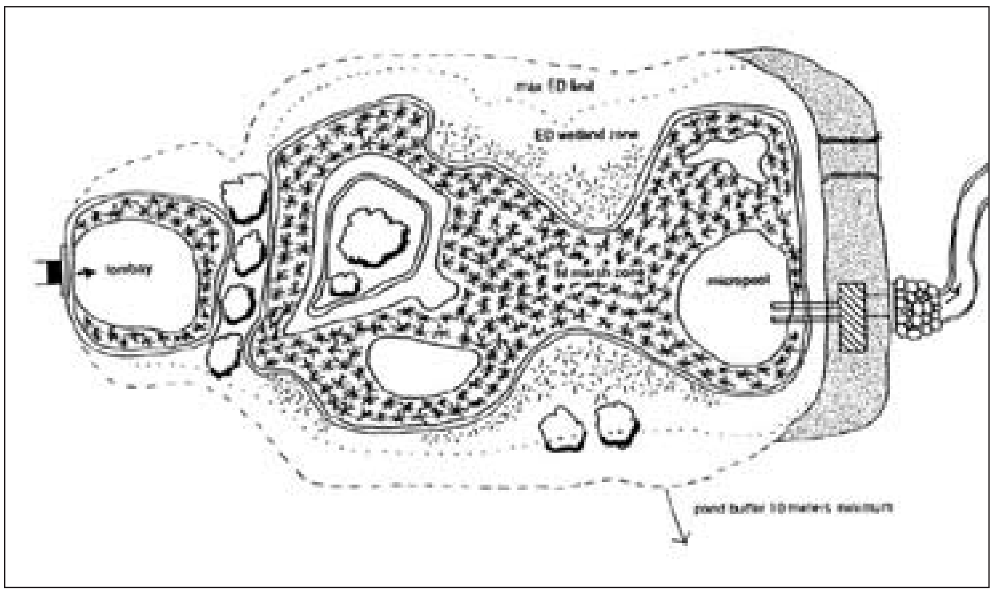


Figure 3:Extended Detention Wetland System, *Source: Schueler, 1992*

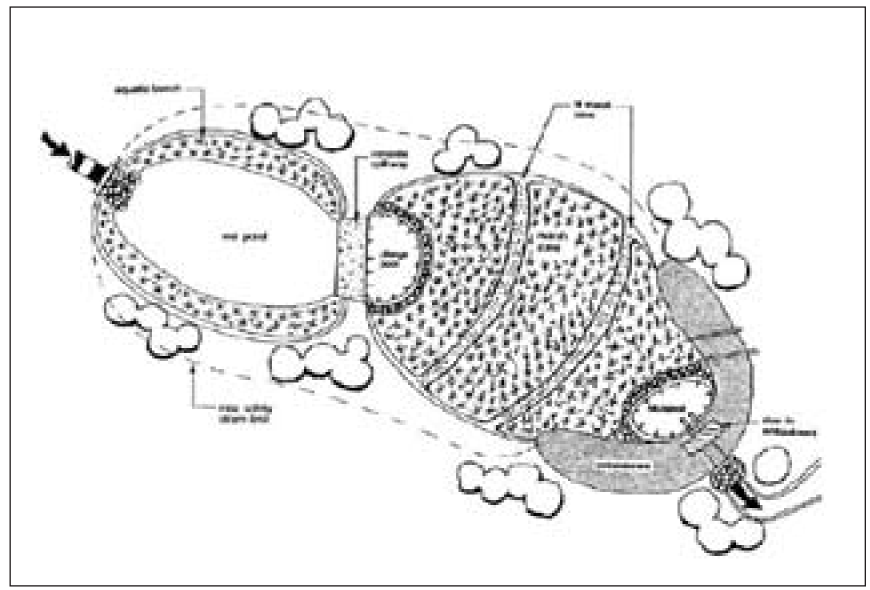


Figure 4:Pond/Wetland System, *Source: Schueler, 1992*

Table 1: Summary of Pollutant Removal Efficiencies (CWP, 1997)

Pollutant	Removal Efficiency
Plant Nutrient	
Total Phosphorus	49%
Total Nitrogen	28%
Total Suspended Solids	67%
Metals	
Cadmium	36%
Copper	41%
Lead	62%
Zinc	45%
Organic Carbon	34%
Petroleum Hydrocarbons	
Bacteria	77%

Limitations

Stormwater wetlands can cause adverse environmental impacts within the wetland itself and downstream of the wetland. Communities may be opposed to a wetland due to the potential of a mosquito breeding area, other nuisances or the wetlands' appearance. Other notable limitations include:

- Release of nutrients outside of the growing season
- Difficulty maintaining vegetation under a variety of flow conditions
- Geese may become undesirable year-round residents if natural buffers are not included in the wetland design
- May act as a heat sink, and can discharge warmer water to downstream water bodies
- Depending upon design, greater land space required than for other BMPs
- Until vegetation is established or during non-growing seasons, pollutant removal efficiencies may be lower than anticipated
- Relatively high construction costs relative to other BMPs

Sizing and Design Guidance

A site appropriate for a wetland must have an adequate water flow and appropriate underlying soils. Baseflow from the drainage area or groundwater must be sufficient to maintain a shallow pool in the wetland and support the vegetation, including species susceptible to damage during dry periods. Underlying soils that are type B,C or D will have only low infiltration rates. Sites with type A soils will have high infiltration rates and may require a geotextile liner.

The design criteria for stormwater wetlands are the same as those for active settling ponds. They can be designed to meet particle size removal efficiencies and treatment volume criteria. Factors which increase the settling rate of suspended solids in stormwater wetland include:

- Laminar settling in zero-velocity zones created by plant stems
- Anchoring of sediments by root structure, helping to prevent scour in shallow areas
- Increased biological activity removing dissolved nutrients

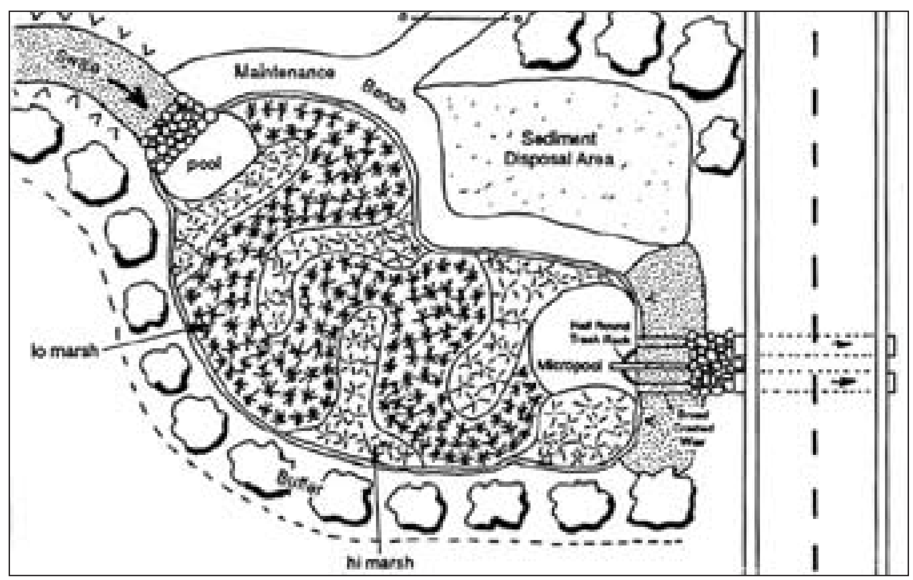


Figure 5: Pocket Wetland, *Source: Schueler, 1992*

- Increased biological flow formation

Design criteria and other considerations for the four wetland types are summarized in Table 2.

Extended detention within the wetland increases the time for sedimentation and other pollutant removal processes to occur and also provides attenuation of flows. Fifty percent of the treatment volume can be added into the wetland system for extended detention. Extended detention should be detained between 12 and 24 hours.

Sediment forebays decrease the velocity and sediment loading to the wetland. They also create sheet flow, extend the flow path, and prevent short-circuiting. A micropool just prior to the outlet will also prevent outlet clogging. The forebay and micropool should contain at least 10 percent of the wetland's treatment volume and should be 4 to 6 feet deep.

Wetland vegetation can be established by any of five methods: mulching, allowing volunteer vegetation to become established, planting nursery vegetation, planting underground dormant parts of a plant and seeding. Appropriate plant types vary with location and climate. A wetland designer should select five to seven plants native to the area.

Table 2: Stormwater Wetland Design Criteria (Schueler, 1992)

	Stormwater Wetlands			
Design Criteria	Shallow Marsh	Extended Detention (ED) Wetland	Pond/Wetland System	Pocket Wetland
Wetland/Watershed Ratio	0.02	0.01	0.01	0.01
Minimum Drainage Area	25 acre	10 acre	25 acre	1-10 acre
Length to Width Ratio (minimum)	1:1	1:1	1:1	1:1
Extended Detention (ED)	No	Yes	No	No
Allocation of Treatment Volume (pool, marsh, ED)	20/40/40	20/35/45	45/25/30	10/40/50
Allocation of Surface Area (deep water, low marsh, high marsh)[1]	20/40/40	20/35/45	45/25/30	10/40/50
Cleanout Frequency	2-5 yrs	2-5 yrs	10 yrs	2-5 yrs
Forebay	Required	Required	No	Optional
Micropool	Required	Required	Required	Optional
Buffer	25 to 50 ft	25 to 50 ft	25 to 50 ft	0 to 25 ft
Pondscaping Plan Requirements	Emphasize wildlife habitat marsh microtopography, buffer	Emphasize stabilization of ED zone, project pondscaping zones	Emphasize wildlife habitat and hi marsh wedges	Pondscaping plan optional

Note: 1. Deep water – 1.5 to 6 feet below normal pool level
Low marsh – 0.5 to 1.5 feet below normal pool level
High marsh – 0.5 feet below normal pool level

Cost

Costs incurred for stormwater wetlands include those for permitting, design, construction and maintenance. Permitting cost can vary by state and local regulations, but permitting, design and contingency costs are estimated at 25 percent of the construction costs (EPA, 1999). Stormwater wetland with a sediment forebay can range in cost, from $26,000 to $55,000 per acre of wetland (EPA, 1999). This includes costs for clearing and grubbing, erosion and sediment control, excavating, grading, staking, and planting. Other sources have reported typical unit base cost for stormwater wetlands range from $0.60 to $1.25 per cubic feet (CWP, 1998). Maintenance costs for wetlands are estimated at 2 percent per year of the construction costs (CWP, 1998)

Maintenance

A detailed maintenance plan must be developed which specifies short and long-term maintenance of the wetland. The maintenance plan should include the following at a minimum (MIDEQ, 1997):

- Specify what individual or agency is responsible for which maintenance items. If several agencies are involved each must agree to do their portion of the maintenance.
- Inspect the wetland twice a year and after major storm events. Initially, determine if it is working according to design, look for signs of eroding banks or excessive sediment deposits and insure that plant growth is occurring as expected. Routine inspections should include looking for clogged outlets, dike erosion and nuisance animals. Be sure to specify what measures to take to correct any defects.
- Determine what the maximum sediment accumulation in the forebay and micropool can be from the design. Sediment accumulation should not reduce the treatment volume to less than 10% of the total wetland treatment volume. Specify how to measure the sediment accumulation, how to remove excess sediment and where to dispose of it.
- Remove floatables and trash as necessary.
- Inspect structures such as riprap or concrete for signs of damage. Inspect and test any mechanical structures such as gates, valves or pumps.
- Mow the banks and access roads at least twice per year to prevent the growth of woody vegetation.
- Harvesting (the periodic annual or semiannual cutting and removal of wetland vegetation) is sometimes recommended to maintain the capability of the wetland to remove soluble nutrients and pollutants.
- Harvesting the vegetation promotes plant growth and thereby the uptake of soluble nutrients and pollutants from stormwater. A written harvesting procedure should be prepared by a qualified wetland scientist. The plan should include how to dispose of harvested material.
- Harvesting vegetation within a natural wetland is often difficult due to the topography and thick organic soils present. However, a constructed wetland can be designed in a manner that decreases harvesting and maintenance practices and associated costs.

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Bioretention

Introduction

The bioretention filter (also referred to as a "rain garden" or a "biofilter") is a stormwater management practice to manage and treat stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. The method combines physical filtering and adsorption with bio-geochemical processes to remove pollutants. The system consists of an inflow component, a pretreatment element, an overflow structure, a shallow ponding area (less than 9" deep), a surface organic layer of mulch, a planting soil bed, plant materials, and an underdrain system to convey treated runoff to a downstream facility (see Figure 1).

Facility Application

The bioretention facility is one of the more versatile structural stormwater management measures. The practice can be applied to manage almost every land use type from very dense urban areas to more rural residential applications. It is ideally adapted for ultra-urban redevelopment projects. The only limitation is on using bioretention is as a so-called "exfilter," (an exflter is where the system is designed to first filter runoff through the soil media before infiltration into the underlying soil) in poor soils, high groundwater, or where soil contamination would prevent conventional infiltration.

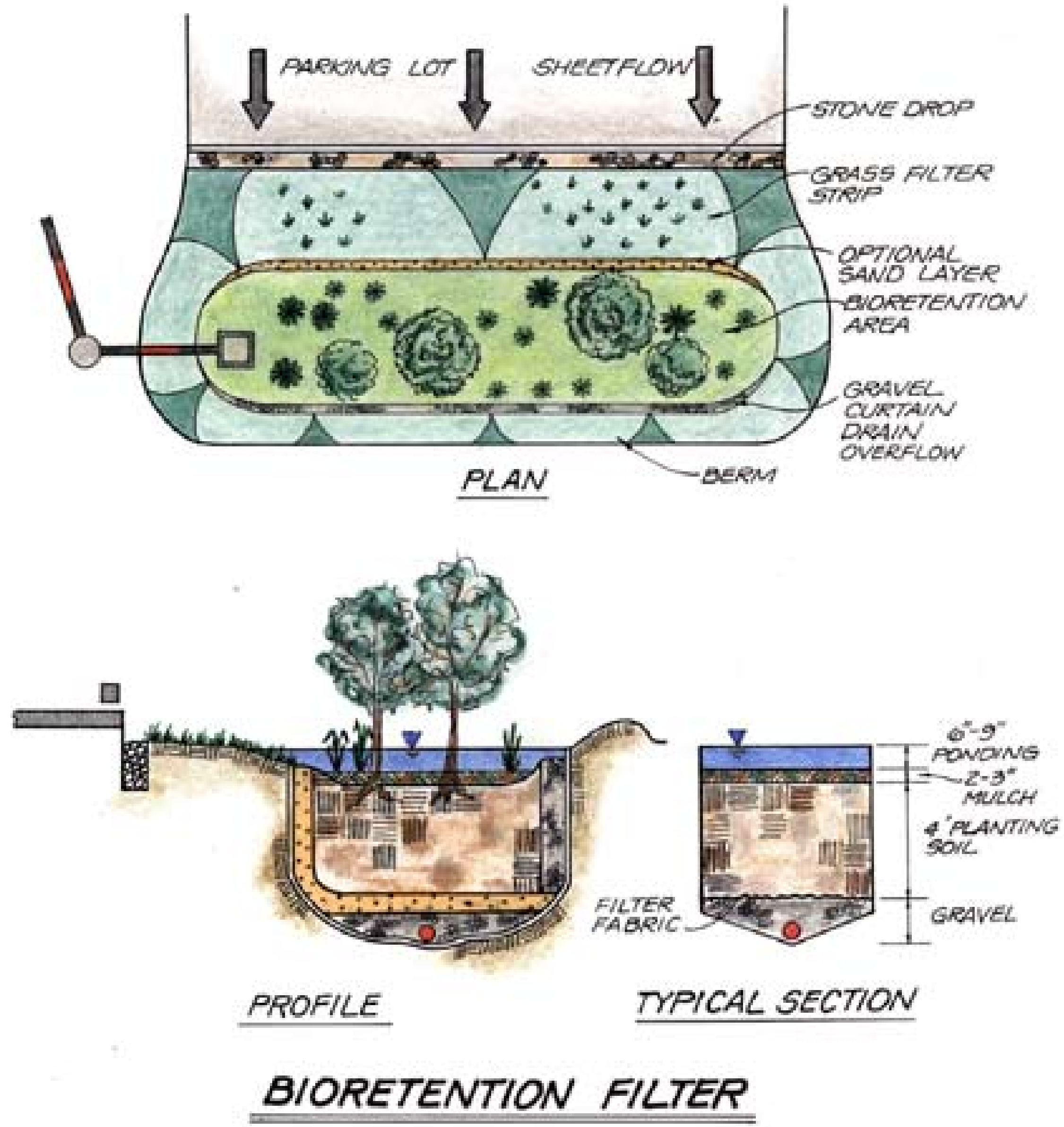

Figure 1: Schematic and Photo of Bioretention Filter, Source: Claytor & Schueler, 1996

The bioretention system is intended to capture and manage relatively small volumes of water from relatively small drainage areas (generally less than five acres). So consequently, the system is rarely utilized on the watershed scale to manage large drainage areas. The system also is rarely used to manage large storms or to provide peak flow attenuation for the so-called "channel forming" storms (i.e, in the range of the 1-year to 1.5-year frequency return interval), or flood control events (i.e., 10-year to 100-year frequency return intervals).

Table 1: Pollutant Removal Performance of Bioretention Facility (Davis, et. al., 1998)

Field Test of Bioretention Filter in Prince Georges County, Maryland		
Pollutant Parameter	**% Removal**	**Outflow Concentration (mg/l)**
Total Phosphorus	65	0.18
Total Nitrogen	49	2.0
TKN	52	1.7
Ammonia-nitrogen	92	0.22
Nitrate-nitrogen	16	0.33
Copper	97	0.002
Lead	95	<0.002
Zinc	95	<0.025

Benefits

Bioretention can have many benefits when applied to redevelopment and infill projects in urban centers. The most notable include:

- Effective pollutant treatment for solids, metals, nutrients and hydrocarbons (see pollutant removal performance, Table 1);
- Groundwater recharge augmentation (if designed as an exfilter, where soils, land uses, and groundwater elevations permit);
- Micro-scale habitat and reduction of urban "heat island" effects;
- Aesthetic improvement to otherwise hard urban surfaces;
- Ease of maintenance, coupling routine landscaping maintenance with effective stormwater management control;
- Safety. The bioretention system is a very shallow depression that poses little risk to vehicles, children or the general public;

Bioretention filter for street runoff.
Source: Claytor

Limitations

Bioretention facilities have some limitations that restrict their application. The most notable of these include:

- Steep slopes. Bioretention requires relatively flat slopes to be able to accommodate runoff filtering through the system.
- Direct entry of runoff at the surface of the facility. The bioretention system is designed to receive runoff from sheet flow from an impervious area or by entry by a roof drain downspout. Because the system works by filtration through a conditioned planting media, runoff must enter at the surface. If drainage is piped to the treatment area, runoff may enter the facility several feet below grade, thus requiring significant excavation.
- Minimum head requirements. Again, because the system is designed to filter runoff through the soil media, a minimum head is required. The typical cited valued is 5' between the surface and the discharge pipe, which can be reduced where the soil media depth is reduced and augmented with compost or other additives for enhanced pollutant removal.
- Bioretention facilities alone, rarely meet all stormwater management objectives. If channel protection and/or flood controls are necessary for a given project, another

practice is generally required.

- Bioretention requires a modest land area to effectively capture and treat runoff from storms up to approximately the 1-inch precipitation event (i.e., approximately 5% of the impervious area draining to the facility).

Sizing and Design Guidance

Bioretention facility surface areas are typically sized at a ratio of 5% of the impervious area draining to the facility to capture, manage, and treat runoff from the 1-inch precipitation event (Claytor & Schueler, 1996). The basis for this guideline relies on the principles of Darcy's Law, where liquid is passed through porous media with a given head, a given hydraulic conductivity, over a given timeframe. The basic equation for sizing the required bioretention facility surface area is as follows:

$$A_f = Vol*(d_f) / [k*(h_f + d_f)(t_f)]$$

where:

A_f = the required surface area of the bioretention facility (ft^2)
Vol = the treatment volume (ft^3)
d_f = depth of the bioretention system (ft, usually set at 4 ft)
k = the hydraulic conductivity (in ft/day, usually set at 0.5 ft/day, but can be varied depending on the properties of the soil media, up to a maximum of 2 ft/day)
h_f = average height of water above the bioretention bed (usually set at 3 inches)

Bioretention filter for parking lot.
Source: Claytor

t_f = the design time to filter the treatment volume through the filter media (usually set at 72 hours)

The 5% guideline can be modified by changing one or more of the above design variables. For instance, if a designer has a high water table, the depth might be reduced from the typical 4 feet to as low as 18 inches or the media composition might be altered to allow for a higher hydraulic conductivity.

In addition, there are several physical geometry recommendations that should be considered in the layout and design of bioretention facilities. The following design guidance is suggested:

- Minimum width: 10 feet
- Minimum length: 15 feet
- Length to width ratio: 2:1
- Maximum ponding depth: 9 inches
- Planting soil depth: 4 feet
- Underdrain system: 6" pipe in 8" gravel bed
- Plant spacing: trees at 10-foot centers, shrubs at 5-foot centers and herbaceous materials at 1- to 2-foot centers

The minimum width allows for random spacing of trees and shrubs and also allows for the planting densities specified above, which help create a micro-environment where stresses from urban stormwater pollutants, drought, and exposure are lessened. For widths greater than 10 feet, a minimum length to width ratio along the stormwater flowpath of 2:1 is recommended. This longer flowpath allows for the settlement of particulates and maximizes the edge to interior ratio. The recommended maximum ponding depth of 9 inches provides surface storage of stormwater runoff, but is not too deep to affect plant health, safety, or create an environment of stagnant conditions. The ponded water will also dissipate in less than 72 hours (and in most cases within a few hours), which maintains the flexibility in plant species selection.

The bioretention system relies on a successful plant community to create the micro-environmental conditions necessary to replicate the functions of a forested eco-system. To do that, plant species need to be selected that are adaptable to the wet/dry conditions that will be present. A mix of upland and wetland trees, shrubs, and herbaceous plant materials are recommended that are arranged in a random and natural configuration starting from the more upland species at the outer most zone of the system to more wetland species at the inner most zone. Figure 2 illustrates the typical planting zones and Table 2 lists some of the most common native species adapted to New England's climate.

Table 2: Native Plant Guide for Stormwater Bioretention Areas

Trees	Shrubs	Herbaceous Species and Grass-like Plants
Acer rubrum Red Maple	*Hamemelis virginiana* Witch Hazel	*Iris versicolor* Blue Flag
Juniperus virginiana Eastern Red Cedar	*Ilex verticillata* Winterberry	*Lobelia cardinalis* Cardinal Flower
Platanus occidentalis Sycamore	*Viburnum dentatum* Arrowwood	*Rudbeckia laciniata* Cutleaf Coneflower
Salix nigra Black Willow	*Alnus serrulata* Brook-side Alder	*Scirpus cyperinus* Woolgrass
Pinus rigida Pitch Pine	*Cornus stolonifera* Red Osier Dogwood	*Scirpus pungens* Three Square Bulrush

Source: (CWP, 2002)

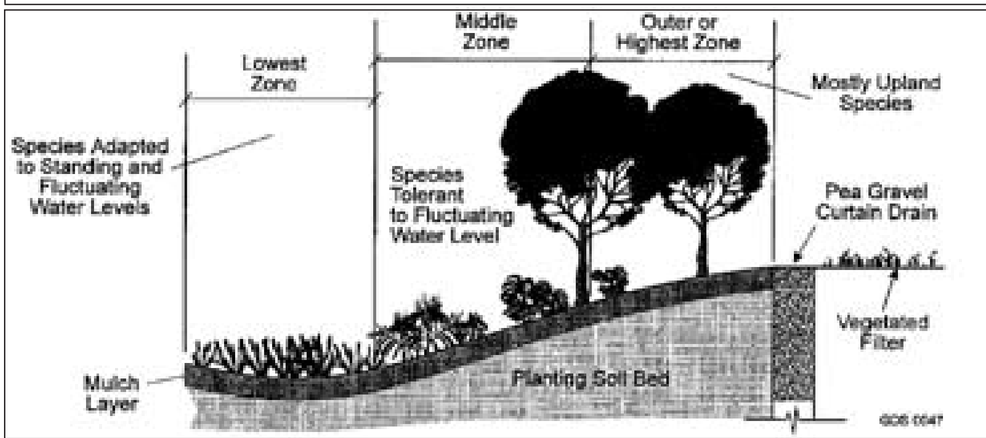

Figure 2: Profile of Bioretention Illustrating Planting Zones

Cost

Bioretention facilities are cost-effective measures designed to help meet many of the management objectives of watershed protection. Because these practices are typically sized as a percentage of the impervious area, the cost is relatively constant with drainage area. Unlike retention ponds and constructed stormwater wetlands, whose cost decreases with increasing drainage area, bioretention does not benefit from economies of scale. Typical capital construction costs are in the range of approximately \$5 to \$6 per cubic foot of storage. Another method of estimating cost is based on the impervious cover treated. Bioretention facilities range from approximately \$18,000 to \$20,000 per impervious acre (CWP, 1998). Annual maintenance cost is approximately 5 to 7% of capital construction costs or in the range of \$900 to \$1,000 per impervious acre treated.

Maintenance

Inspections are an integral part of system maintenance. During the six months immediately after construction, bioretention facilities should be inspected at least twice, or more, following precipitation events of at least 0.5 inch to ensure that the system is functioning properly. Thereafter, inspections should be conducted on an annual basis and after storm events of greater than or equal the 1-year precipitation event (approximately 2.6 inches in Rhode Island). Minor soil erosion gullies should be repaired when they occur. Pruning or replacement of woody vegetation should occur when dead or dying vegetation is observed. Division of herbaceous plants should occur when over-crowding is observed, or approximately once every 3 years. The mulch layer should also be replenished (to the original design depth) every other year as directed by inspection reports. The previous mulch layer would be removed, and properly disposed of, or roto-tilled into the soil surface. If at least 50 percent vegetation coverage is not established after two years, a reinforcement planting should be performed. If the surface of the bioretention system becomes clogged to the point that standing water is observed on the surface 48 hours after precipitation events, the surface should be roto-tilled or cultivated to breakup any hard-packed sediment, and then revegetated.

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Example of a Vegetated Infiltration Basin "Rain Garden"

Source: City of Portland, Stormwater Management Manual, 2002

Green Rooftop Systems

Introduction

A green roof is created by adding a layer of growing medium and plants on top of a traditional roof system. Green roofs are becoming more commonly used for stormwater management, and are suitable for urban retrofits as well as for new buildings. A green roof is different from a roof garden. A roof garden consists of freestanding containers and planters on a terrace or deck.

Green roofs consist of the following components, starting from the top down (Figure 1):

- Plants, often specially selected for particular application
- Engineered growing medium
- Landscape or filter cloth to contain the roots and the growing medium, while allowing for water to filtrate below the surface into the medium
- Drainage layer
- Waterproofing / roof membrane, with an integral root repellent
- Roof structure, with traditional insulation

Excess precipitation (beyond what is absorbed by the medium) filters through the growing medium and is collected in the drainage layer. The drainage layer may contain a built-in water reservoir. The remaining stormwater is then drained into a conventional downspout. During large storm events there is an overflow drain to minimize ponding on the rooftop.

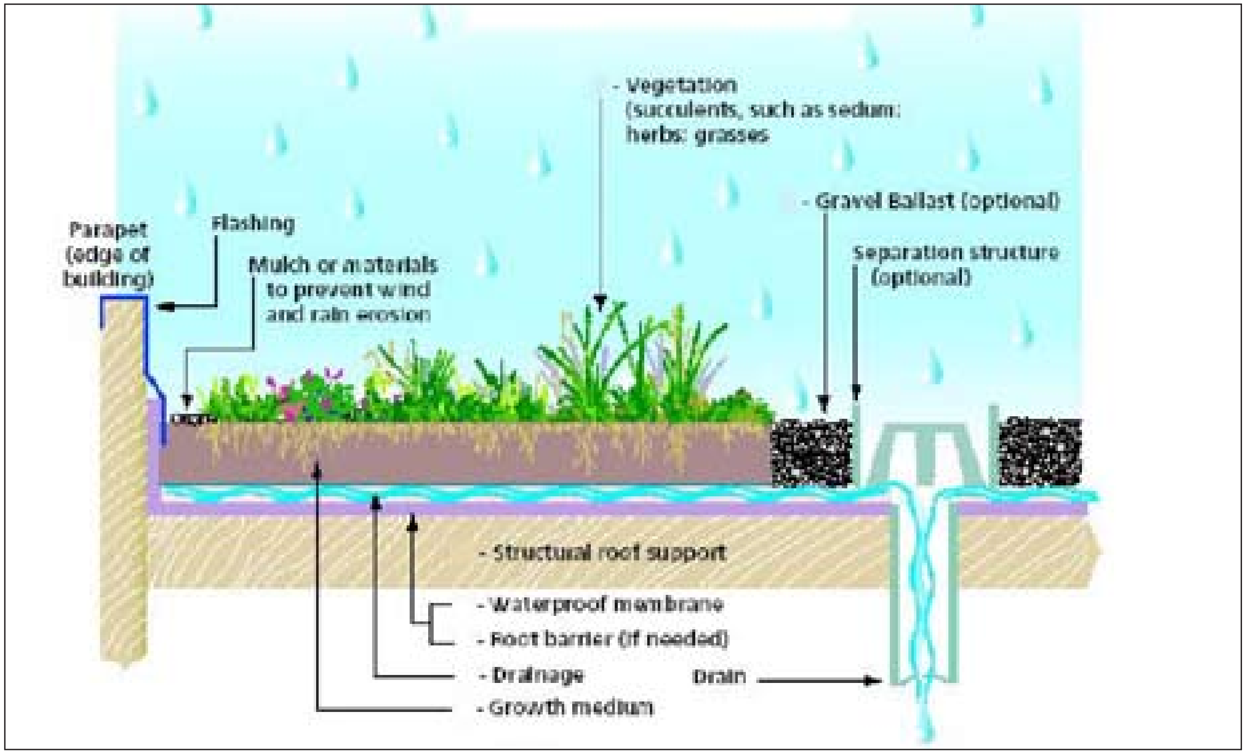

Figure 1: Schematic Cross Section of a Green Roof
Source: City of Portland, Stormwater Management Manual, 2002

Facility Application

There are two different types of green roofs: extensive and intensive. Extensive green roofs are often not accessible and are generally characterized by low weight, low capital cost, low plant diversity, and minimal maintenance requirements (Figure 2). Intensive green roofs often have pedestrian access and are characterized by deeper soil and greater weight, higher capital cost, increased plant diversity, and more maintenance requirements (Fig. 3).

Figure 2: Photo of Extensive Green Roof
Source: City of Portland, Stormwater Management Manual, 2002

Extensive roofs typically have a mineral base mixture of sand, gravel, crushed brick, leca, peat, organic matter and some soil as the growing medium. These are generally lighter than saturated soil. The growing medium depth ranges from 2 to 6 inches with a weight increase from a range of 16 to 36 lbs/sf when fully saturated. Due to the shallowness of the growing medium and the extreme desert-like condition on many roofs, the selected plants will need to be low and hardy. Figure 4 illustrates a cross sectional schematic of a proprietary extensive roof.

Intensive rooftops often have a soil-based growing medium, ranging from 8 to 24 inches. This increases the loading weight from the saturated soil from a range of 60 to 200 pounds per square foot (lbs/sf) (Peck and Kuhn). With an intensive roof, plant selection is more diverse and can include trees and shrubs due to the relatively deep growing medium. This allows for the development of a more complex ecosystem but with this diversity a higher level of maintenance is required. Figure 5 illustrates a cross sectional schematic of a proprietary intensive roof. Table 1 compares the advantages and disadvantages of an extensive and intensive green roof system.

Green roofs may not be suitable to heavy industrial areas. These areas are prone to high levels of dust and/or chemicals in the air that may cause damage to plants. Another limitation to green roofs in stormwater management is its quantity control capability. Green roofs do not provide flood control or channel protection for any storm greater than 1-inch and do not provide recharge to groundwater unless a separate infiltration system is designed on site.

Figure 3: Photo of Intensive Green Roof
Source: City of Portland, Stormwater Management Manual, 2002 & American Hydrotech Inc.

Benefits

Green roofs provide many benefits both privately and publicly. Direct benefits to private owners may include:

- **Energy Savings** – Green roofs provide insulation from the heat and the cold. The amount of energy required to heat or cool a building is reduced.
- **Extend Life of Roof** – Green roofs protect roofing membranes from extreme temperature fluctuations and the negative impacts of ultraviolet radiation.
- **Sound Insulation** – Green roofs can be designed to insulate against outside noises.
- **Fire Resistance** – When fully saturated, green roofs can help stop the spread of fire to and from building rooftops.

The two major public benefits from green roofs are a major reduction in urban heat island effects and stormwater retention capability. Urban heat island is the overheating of urban and suburban areas, due to increased paved, built-over, and hard surface areas. The urban heat island effect increases electricity and air conditioning costs. Green roof tops intercept and absorb solar radiation that would otherwise

Table 1: Comparison of Extensive and Intensive Green Roof Systems (CMHC, 1998)

Extensive Green Roof	Intensive Green Roof
Advantages:	**Advantages:**
Lightweight; roof generally doesn't require reinforcement	Greater diversity of plants and habitats
Suitable for large roof areas.	Good insulation properties
Suitable for sloped roofs (up to 30 degree slope)	Can simulate a wildlife garden
Low maintenance and longer life	Aesthetically pleasing
No need for irrigation and specialized drainage system	Accessible, providing diverse utilization of the roof. i.e. recreation, growing food, open space
Less technical expertise needed	Greater stormwater retention capabilities
Often suitable for retrofit projects	Longer membrane life
Relatively inexpensive	
Disadvantages:	**Disadvantages:**
Less energy efficient and stormwater retention benefit	Greater weight loading on roof and cost
Limited choice of plants	Need for irrigation and drainage system
No access for recreation or other use	Higher capital and maintenance costs

strike dark roof surfaces and be converted into heat.

Green roofs can be designed as effective stormwater management controls. The growing medium on both intensive and extensive green roofs can act as a stormwater pre-treatment system. The method combines physical filtering and adsorption with bio-geochemical processes to remove pollutants. Green roofs can be designed for stormwater retention capability, therefore reducing the overall stormwater runoff volume from rooftops. Stormwater retention rates are determined by saturated filtration capacity, thickness of growing medium, field capacity, porosity, under-drainage layer, water retention, flow, and relief drain spacing. A heavily vegetated green roof with 8 to 16 inches of growing medium can hold 4 to 6 inches of water (Peck and Kuhn).

Limitations

Green roofs are best suited for new buildings, where structural considerations can be incorporated early in the design phase. Retrofits to existing buildings are possible, however, the limiting factor when dealing with retrofitting is the additional loading to the rooftop. Saturated soil weighs approximately 100 lbs/sf, existing roofs are typically designed for a live load of 40 lbs/sf, which includes snow load. As stated earlier an extensive system can weigh 16 to 36 lbs/sf and an intensive system can weigh 60 – 200 lbs/sf, fully saturated. A landscape architect or horticulturist can advise on certain plants that do not require a deep soil layer, therefore reducing the weight on the roof.

Other limiting factors are the initial costs and maintenance costs of a green rooftop. Installation costs for green rooftops are considerably higher (25% to 300%) than those for conventional roofs. Maintenance costs can range from $1.25 to $2.00 per square foot annually, depending on the system.

Sizing and Design Considerations

To design and implement green rooftops, the following issues need to be considered:

- Condition of the existing roof is important. The most cost effective time to construct a green roof is when a roof needs to be replaced or newly constructed. A waterproof membrane and root resistance layer will need to be placed on all rooftops.
- Structural capacity of the roof will dictate the type of green roof that can be built.
- Access to the roof is an important consideration. Depending on the type of green roof, safe public access may be required. In addition, access to transport materials for construction and maintenance will be required.

- The weight of the green roof must not exceed the structural capacity of the roof.
- On top of the cost for construction, materials, and permits the cost for specialist, such as structural engineers or horticulturists and any needed structural and safety improvements, should be taken into consideration.

Components of a green roof can be bought and installed separately, or proprietary assembly can be purchased. In either case, the basic components starting from the roof up are the following:

- Insulation layer, a waterproof membrane to protect the building from leaks, and a root barrier to prevent roots from penetrating the waterproof membrane.
- Drainage layer, usually made of lightweight gravel, clay or plastic. The drainage layer keeps the growing media aerated and can be designed to retain water for plant uptake at a later time.
- Geotextile or filter fabric that allows water to soak through but prevent erosion of fine soil particles.
- Growing media that helps with drainage while providing nutrients for plant uptake.
- Plants, typically for extensive green roofs,

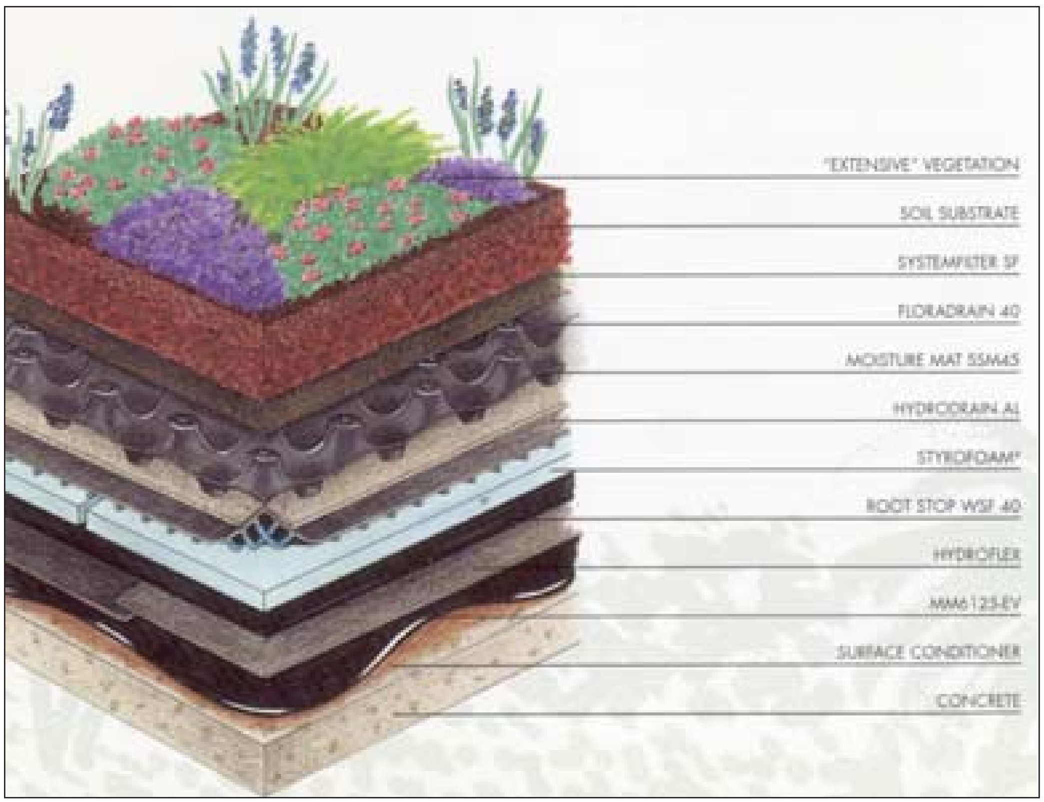

Figure 4: Schematic Cross Section of An Extensive Green Roof, Source: American Hydrotech Inc.

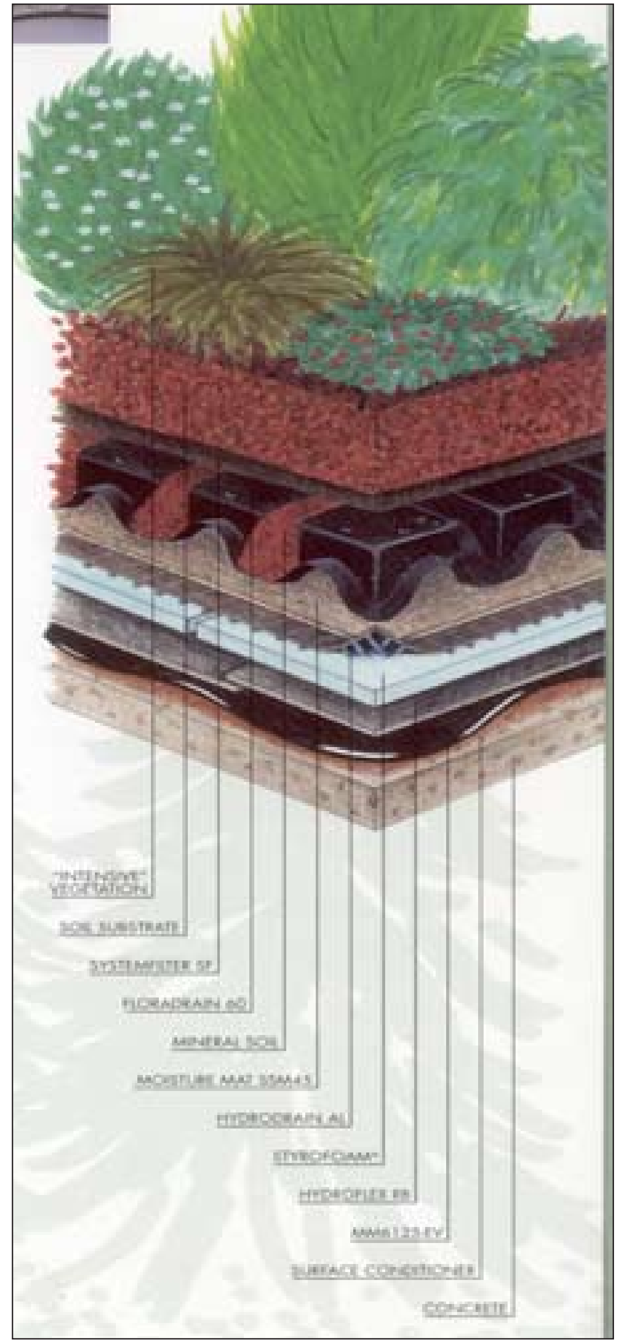

Figure 5: Schematic Cross Section of an Intensive Green Roof, Source: American Hydrotech Inc.

a mixture of grasses, mosses, sedums, sempervivums, festucas, irises and wildflowers that are native to drylands, tundras, alvars and alpine slopes. For intensive green roofs, with few exceptions the choices are limitless. See Table 2 for an example of plant species used by the City of Chicago, City Hall Green Rooftop.

- A wind blanket, used to keep the growing media in place until the root of the plant take hold.

Table 2: Plant List for the City Hall in Chicago (City of Chicago, 2001)

Extensive Green Roof Systems	
Latin Name	**Common Name**
Achillea millefolium	Yarrow
Allium canadense	Wild onion
Allium cernuum	Nodding wild onion
Linaria vulgaris	Butter-and-eggs
Ruellia humilis	Hairy ruellia
Sedum acre	Wall pepper
Sedum album	White stonecrop
Sedum reflexum	Rock stonecrop
Sedum sarmentosum	Stringy stonecrop
Sedum spurium	False wild stonecrop
Verbena simplex	Narrow-leaved vervain
Viola sororia	Common blue violet

Intensive Green Roof Systems			
Perennials		**Grasses**	
Latin Name	**Common Name**	**Latin Name**	**Common Name**
Anemone cylindrica	Thimbleweed	*Buchloe dactyloides*	Buffalo grass
Anemone patens wolfgangiana	Pasque flower	*Danthonia spicata*	Poverty oat grass
Asclepias tuberosa	Butterfly weed	*Panicum oligosanthes*	Prairie dropseed
Aster ericoides	Heath aster		
Aster laevis	Smooth blue aster	**Shrubs**	
Aster oblongifolius	Aromatic aster	*Ceanothus americanus*	New Jersey tea
Campanula rotundifolia	Harebell		
Chrysanthemum leucanthemum	Ox-eye daisy		
Coreopsis lanceolata	Sand coreopsis		
Echinacea purpurea	Purple coneflower		
Geum triflorum	Prairie smoke		
Heuchera richardsonii	Prairie alum root		
Lespedeza capitata	Round-headed bush clover		
Monarda fistulosa	Wild bergamot		
Pedicularis canadensis	Wood betony		
Penstemon digitalis	Foxglove beard tongue		
Petalostemon purpureum	Purple prairie clover		
Physostegia virginiana	Prairie obedient plant		
Potentilla simplex	Common cinquefoil		
Ratibida columnifera	Mexican hat		
Ratibida pinnata	Yellow coneflower		
Rudbeckia hirta	Black-eyed susan		
Solidago nemoralis	Old-field goldenrod		
Tradescantia ohiensis	Common spiderwort		
Verbena stricta	Hoary vervain		
Zizia aurea	Golden alexanders		

Cost

All green roofs share common components, however there are no standard costs for implementation. In the US the cost range for extensive roof systems ranges from $15 to $20 per square foot (SF) (Scholz-Barth, 2001). Table 3 below summarizes the range of component costs for an existing building with sufficient loading capacity.

Maintenance

Maintenance of a green roof system requires plant maintenance as well as maintenance to the waterproof membrane. Depending on whether the green roof is an extensive or intensive system, the plant maintenance will range from two to three yearly inspections to check for weeds or damage, to weekly visits for irrigation, pruning and replanting.

Regular maintenance inspections should be scheduled, as for a standard roof inspection. Any leaks in the roof should be checked out immediately. Green roofs protects the waterproof membrane from puncture damage and solar radiation, however, leaks can occur at joints, penetrations and flashings, due more to installation than material failure. Drains should also be inspected for possible breach in filter cloth and cleaned on a regular basis.

Table 3: Component Cost for Extensive and Intensive Green Roof Systems (modified from Peck and Kuhn)

	Cost	
Component	**Extensive System**	**Intensive System**
Design & Specifications	5% - 10% of total roofing project cost	5% - 10% of total roofing project cost
Project Administration & Site Review	2.5% - 5% of total roofing project cost	2.5% - 5% of total roofing project cost
Re-Roofing with Root Repelling Membrane	$10.00 - $15.00 per SF	$10.00 - $15.00 per SF
Green Roof System (curbing, drainage layer, filter cloth, and growing medium)	$5.00 - $10.00 per SF	$15.00 - $30.00 per SF
Plants	$1.00 - $3.00 per SF	$5.00 - $200.00 per SF[1]
Installation & Labor	$3.00 - $8.00 per SF	$8.00 - $18.00 per SF
Maintenance	$1.25 - $2.00 per SF (for the first 2 years)	$1.25 - $2.00 per SF (annually)
Irrigation System (if necessary)	Typically Not Needed	$2.00 - $4.00 per SF
Fencing and/or Guardrail	Not Applicable	$20.00 - $40.00 per linear feet
Unit Cost	$22.00 - $42.00 SF	$41.00 - $269.00 per SF[2]
Total Unit Cost	**$24.00 - $48.00 per SF**	**$44.00 - $309.00 per SF**

Note:

1 – One tree may cost $200 - $500

2 – Unit cost does not include fencing and/or guardrail

References

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